ELEMENTARY MICROSCOPY

F. SHILLINGTON SCALES

ELEMENTARY MICROSCOPY

ELEMENTARY
MICROSCOPY

A Handbook for Beginners

BY

F. SHILLINGTON SCALES, F.R.M.S.

LONDON
BAILLIÈRE, TINDALL AND COX
8 HENRIETTA STREET, COVENT GARDEN
1905

TO

M. S. S.

PREFACE

THE groundwork of this little book originally appeared as a series of articles written by the author under the title of 'Microscopy for Beginners.' They were continued for eighteen months, and appeared to so far attain the purpose for which they were written as to justify their republication in book form. For this purpose they have been almost entirely rewritten and recast. The author desires to disclaim any idea of comparison with larger and more elaborate works, and has confined himself strictly to the microscope itself, leaving its applications to be sought for elsewhere. He has endeavoured throughout to keep in view the wants of the beginners for whom he originally wrote, and to give that practical information and advice as to the choice of a microscope and its accessories, their uses, and the more elementary methods of preparing objects for the microscope, which experience has taught him the beginner most needs. He has tried also to explain, without technicalities or too much detail, the principles underlying microscopical practice, methods, and technique.

Thanks are due to many firms for their ready courtesy in lending many of the illustrations, several of which have been especially made.

JESUS COLLEGE, CAMBRIDGE,
February, 1905.

CONTENTS

LIST OF ILLUSTRATIONS

ELEMENTARY MICROSCOPY

CHAPTER I

INTRODUCTORY

In few things is a little initial advice and help more valuable than when one is first taking up the use of an instrument like the microscope. There are many who are desirous of purchasing a microscope, and then learning how to use it, who feel bewildered by the multiplicity of stands and accessories advertised by the various English and Continental makers. There are others who already possess microscopes, but have not yet mastered even the principles of an instrument which is essentially one of precision, and so fail to use their microscopes to advantage, with the result that they soon relegate them to comparative obscurity when the first novelty of possession has departed. There are yet others who use the microscope in scientific work, but even they have not mastered these principles, and scarcely realize how much their work might be facilitated by doing so. Several excellent manuals are to be obtained on the subject, but they deal for the most part with more advanced microscopy and with its applications, whilst the keen competition amongst our leading opticians, and the constant change and

progress to which it gives rise, render a not inconsiderable portion of such books quickly out of date. The aim of the present work is simply first to indicate to the beginner, who, with much enthusiasm, little or no knowledge, and perhaps not too well lined a purse, proposes to take up study with the microscope, how he may to most advantage spend his money on the necessary outfit—what, in fact, are the essential requirements he must look for in his instrument, together with its accessories—and then to explain in detail its manipulation and management. Theory will not be more fully entered into than is necessary for explanatory purposes, and whilst an attempt is made to give instruction on elementary methods of preparing objects for the microscope, it has been decided that Nature, as revealed by the microscope, is quite outside the scope of this little book. The suggestions as to the choice of a microscope are not directed to providing an outfit suitable only for whiling away a pleasant hour or two—for 'looking at pictures,' in fact. Instead, it is the writer's aim to so advise the beginner that afterwards, when he has gained experience for himself, he may feel that what he has bought is not only capable of showing him the infinitely little in Nature as a pastime or pursuit, but will enable him, if he so desires, to do real and serious work in medicine, in zoology, in botany, or in any other of the countless ways in which the modern microscope has become a necessity, and to use the microscope to the best advantage for that purpose.

CHAPTER II

THE SIMPLE AND COMPOUND MICROSCOPE

The Simple Microscope.—Strictly speaking, a microscope may be either **simple** or **compound**. By a simple microscope is understood a lens, or combination of lenses, which magnifies the image but once, and which is generally either held in the hand or provided with some simple

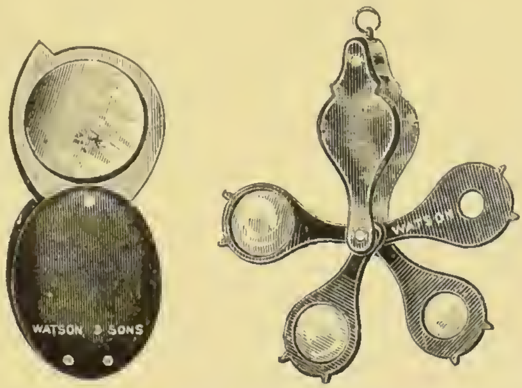

FIG. 1.—EBONITE POCKET MAGNIFIERS.

form of support. Of these, the best known are the ordinary reading-glass, made in all sizes, and the small **pocket magnifiers,** mounted in vulcanite or imitation tortoiseshell, containing one or more lenses (Fig. 1). All these are of the simple double-convex type, and, though cheap, have the drawbacks and imperfections incidental to such a type. They may be obtained from

almost any optician at prices ranging from one shilling upwards. The watchmaker's eyeglass is of this kind.*

Linen Tester.—The **Linen Tester** is of the same description, but is made with a folding support, at the bottom of which is a small square opening in which to count the number of threads to the inch. Another form of simple double-convex lens is mounted on three legs, and the focus is adjusted by means of a screw. This last is sometimes made of two lenses with a diaphragm between.

Coddington Lens. — The **Coddington Lens** is a single double-convex lens which has a groove cut all round the middle, this groove being blackened or filled with black cement so as to act as a limiting diaphragm. The lens itself is of considerable thickness, being really only the central portion of a glass sphere. The performance is very imperfect, and it is now less frequently met with than formerly.

Stanhope Lens.—The **Stanhope Lens** is also a double convex lens, but the curvatures are unequal. In use, the object to be examined is placed on the side with the least convexity, and in actual contact with it, and it is just in focus when the other side of the lens is turned towards the eye. It is obvious that its uses are very limited.

Aplanatic Magnifiers.—Of late years an entirely new form of simple hand-lens has come largely into use, and few working microscopists are without one or more

* The author remembers that a good many years ago an ingenious street-vendor used to sell in the neighbourhood of St. Paul's Churchyard a microscope of this sort made out of a pill-box, with a small hole in the lid, in which was a drop of clear balsam. A similar, but of course temporary, microscope can be made by boring a hole in a blackened card with a red-hot needle, and inserting therein a drop of water.

of these, either for pocket use or for dissecting. These are achromatic triplets, which are also aplanatic. They are often spoken of as 'Steinheil loups.' There are several formulæ adopted by various makers, and there

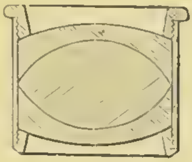

FIG. 2.—STEINHEIL LOUP (SECTION).

is not much to choose between them, but their construction is as illustrated (Fig. 2), and their distinctive features are exquisite definition, freedom from colour, a flat field by means of which the whole of the lens can be

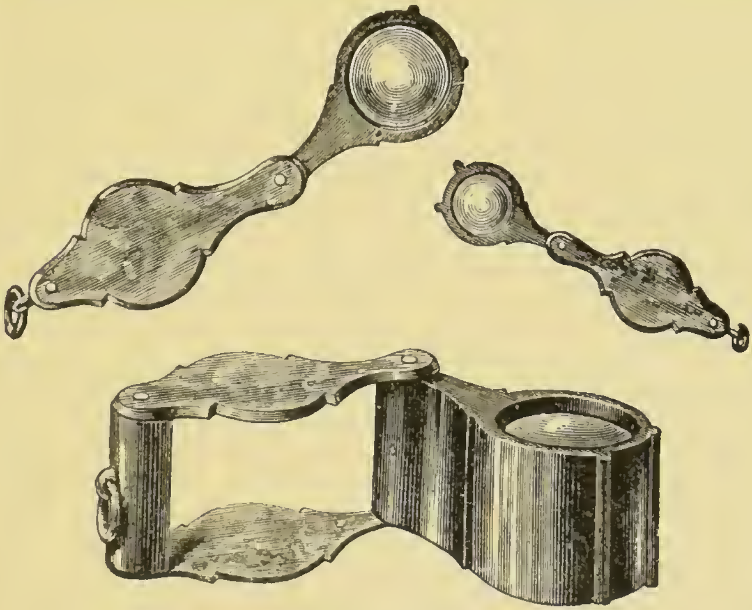

FIG. 3.—PLATYSCOPIC LENSES.

utilized, the image remaining sharply in focus up to the very margin, and ample working distance. In the higher powers particularly they have therefore a marked advantage over the simpler form of lens. Browning

makes these triplets under the name of 'platyscopic' lenses in magnifications of 10, 15, 20, and 30 diameters (Fig. 3). R. and J. Beck supply them with magnifications from 6 upwards in either ebonite or German silver. Chas. Baker, James Swift and Son, and W. Watson and Sons, supply them either in a simple ring to fit into a dissecting holder, or in a mount for the pocket. Leitz and Reichert supply them in dissecting mounts or in pocket mounts, whilst Bausch and Lomb's form is known as the Hastings' triplet. Any of the above lenses may safely be selected, the most convenient power for everyday work being perhaps 6, and after that 10. For a pair 6 and 15 would be handy sizes.

The Compound Microscope.—By a **compound** microscope is understood a combination so arranged that the image given by the first lens is itself magnified again before reaching the eye. These lenses are called respectively the objective and the eyepiece, or ocular. Opaque objects are examined by means of either natural or artificial light reflected from their surfaces, but the vast majority of microscopic objects are specially prepared that they may be viewed by light transmitted through them so as to show their structure. The source of light can be looked at direct, but this would not be convenient in many cases, and therefore beneath the stage holding the object in position is placed a mirror capable of movement so as readily to reflect the light through the object into the lenses. Many microscopes, especially the cheaper Continental stands, make no further provision than this, but the improvement in microscopic objectives and the use of higher powers has necessitated the interposition between the mirror and the object of another lens or system of lenses with which to condense the light, and even accurately focus it upon the object.

These are therefore the elementary essentials of a modern compound microscope, and the following explanations concern the elaborations of these essentials which precision of working has called forth. We propose to leave the explanation of the principles of microscopical vision and of microscopical optics until a later chapter, desiring first to assist our reader to choose his microscope, and to explain its principles and use to him afterwards.

Parts of a Microscope.—Leaving aside for the moment the optical parts of the microscope, it will be observed that the instrument consists of a **foot** or base (Fig. 4), a **stage** to hold the object, a **mirror** to reflect the light; between this and the stage probably a **sub-stage** carrying a **condenser** to condense the light; and a **limb** bearing a **body tube.** Into the lower end of this tube is screwed the **objective,** whilst into the upper end is inserted the **ocular** or **eyepiece,** the tube itself being capable of **coarse adjustment** for focussing, either by sliding bodily in a sleeve or by rack and pinion, and further elaborated by a **fine adjustment** for use with high powers. We shall take all these in turn, explaining them as we proceed.

The Foot.—On the **Foot** depends the stability of the stand as a whole. There are practically two forms—the **pillar and horseshoe** form and the English **tripod.** The advantage of the former is that it is generally a little cheaper, and the sub-stage apparatus is more conveniently manipulated when the microscope must be used in an upright position, as often happens with medical and zoological workers. In any other than the upright position it is much less steady than the tripod form, whilst for horizontal work, especially for photo-micrography, it is quite top-heavy. The ad-

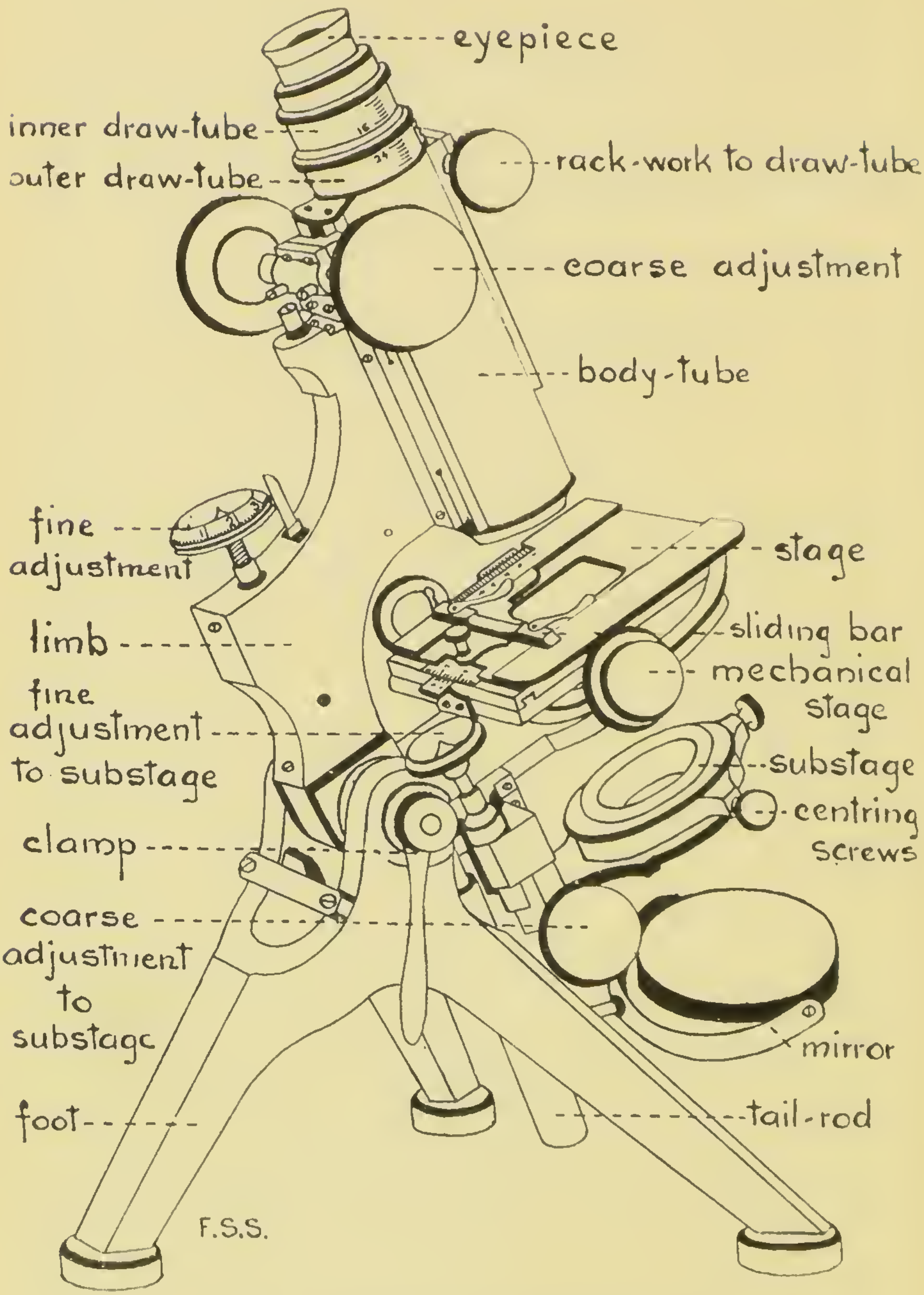

FIG. 4.—PARTS OF A MICROSCOPE.

ditional weight put into this form of stand to remedy the instability is also a disadvantage. The importance of these points can only be fully appreciated and verified by the practical worker, but the tripod foot, either in its ordinary or modified form of bent claw (Fig. 12, p. 33), is daily coming more and more into favour—in England, at any rate—and we unhesitatingly recommend its choice. At the same time, the pillar and horseshoe foot is universal on the Continent, and American makers have borrowed the same model. As a result some of our own makers have been obliged to follow suit. Whatever form of stand be adopted, ascertain that the actual points of contact with the table are not more than three, or a most irritating unsteadiness will result.

The stand must be capable of inclination. It is only the cheapest form of Continental stand for rough laboratory use that is without means of inclination.

The Stage.—The **Stage** should be large and rigid. In its simplest form it will be provided only with two springs to hold the slide in position. These should be adjusted so as not to press too strongly upon the slide, otherwise the fingers will be unable to make the necessary delicate alterations in the position of the object. The surface may be of brass, of vulcanite, or of glass ; for ordinary purposes vulcanite is preferable. The aperture should be large, not less than an inch in diameter, and preferably considerably more. By having a large aperture the end of the finger can be inserted beneath the slide so as to gently raise it when focussing with high powers, the slide being lowered again when the approximate focus is found, and the focus of the objective finally adjusted. By this means the practised microscopist guards against any risk of damaging either his slide or his objective. Mr. E. M. Nelson, who has done

so much for English microscopy, has suggested that the opening shall be cut away right to the front of the stage so as to make a horse-shoe opening, and the suggestion has been adopted in more than one stand, as will be seen when we come to deal with the instruments of individual makers.

Sliding-Bar.—A great improvement upon the ordinary stage springs is a **sliding-bar or carrier,** which slips up and down either in grooves in the stage or outside its parallel edges (Fig. 5). It carries the usual springs.

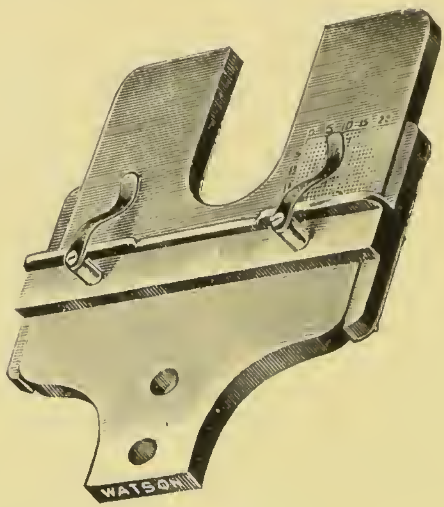

Fig. 5.—Sliding Bar to Stage.

which can be turned aside or brought into use as required. By this means the adjustment of the slide can be carried out with greater precision, and in particular it can be systematically examined by moving alternately the slide horizontally and the bar vertically on the stage.

Mechanical Stage.—In a first-class instrument a further refinement called a **mechanical stage** is necessary (Fig. 6), though for ordinary work the fingers can be trained to a delicacy of adjustment that will cover most requirements. The mechanical stage has two milled

heads which give rectilinear movements horizontally and vertically respectively. The milled heads should preferably be so arranged as not to travel with the stage, otherwise the screws are apt to foul the condenser. The largest and most elaborate stands have a fixed mechanical stage, which may or may not carry a sliding-bar in addition, but all the leading makers have now introduced detachable mechanical stages which

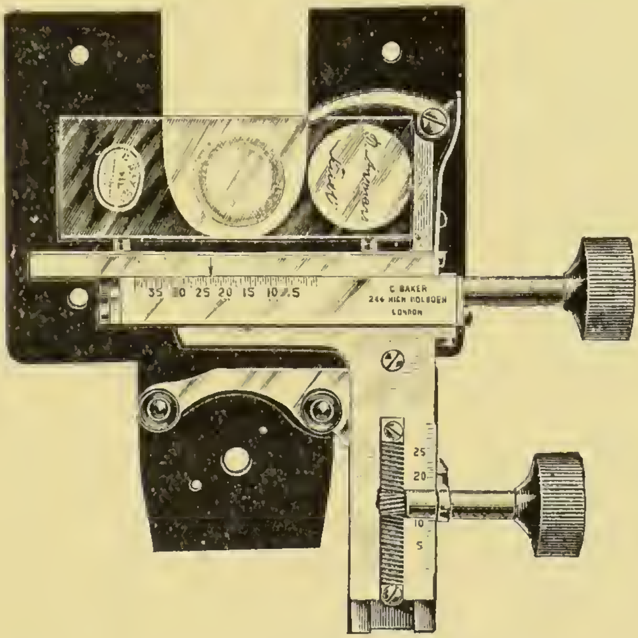

FIG. 6.—DETACHABLE MECHANICAL STAGE.

can in many cases be added as accessories after the purchase of the instrument.

Graduations to Stage.—Yet another refinement is the addition of **graduations** to the stage, both horizontal and vertical, by means of which the position of a slide can be readily noted for future reference, as it is only necessary to replace the slide in the same position to insure a ready finding again of the same field of view. The

graduations are generally ruled off in millimetres, and numbered from 0 to 20 or 30. Where they are marked on a mechanical stage a stop is provided, removable or otherwise, against which to place the corner of the glass slide, and the almost universal adoption now of slides measuring 3 inches by 1 inch renders this easily practicable. In addition, verniers for more exact reading are provided, and by this means rough micrometric measurements can be made in conjunction with a line across the centre of the eyepiece. Other methods will be alluded to when we come to micrometric measurements (pp. 91 and 141).

Rotary Stage.—Microscopes for special purposes, such as petrology, have also a complete rotation to the stage. and the most complete form of instrument is provided not only with this, but with a couple of milled heads just beneath the stage, by means of which the centre of rotation can be made accurately to coincide with the optic axis of the microscope in order to insure an absolutely true rotation. However carefully an objective may be constructed by its maker, it will be found that the optic axis of the microscope varies slightly with each change of objective; but, apart from the necessity of recentring the condenser, this only becomes important or noticeable in case of rotation of the stage. To correct this either the stage must be recentred by means of centring screws provided for the purpose, or the objective itself must be adjusted by means of what is called a **centring nosepiece.** The latter way is cheaper, but naturally lengthens the tube.

The last refinement of all is a rack and pinion by which the stage can be slowly rotated when necessary, and this should be capable of being readily thrown into and out of gear. There may also be graduations in

degrees around the circumference of a circular stage to show the amount of rotation. In its most perfect form the whole of the stage, including the mechanical part, will rotate bodily, though a rotating top plate is not infrequently provided instead, which is less expensive and often of service. A strong protest should be made against the absurdity of providing a microscope with a complete rotating stage, fitted with centring screws, and with elaborate graduations around its entire periphery, but which, owing to the projecting milled heads of the mechanical stage, is incapable of rotation for more than, say, 300 degrees.

Mirror.—The **Mirror** is carried upon a tail rod, either square or circular, and sometimes with an extra joint in it. Under any circumstances it should be capable of being swung aside. In certain microscopes sufficient movement is allowed to enable the mirror to be brought above the stage so as to illuminate an opaque object, and we wonder this is not more frequently met with. For this reason we prefer a circular tail-rod when only one joint is provided, the support of the mirror itself having a corresponding circular clip. The mirror should have two faces, plane and concave; they should be of good size, and be hung in a gimbal so as to give universal movements. The concave mirror having a definite focus, it is necessary that there should be a means of focussing it vertically, but this is generally provided. We have, however, come across microscopes in which the movement was too short to allow of the concave mirror being properly adjusted. The best way to test this is to reflect and then focus the light of a lamp upon a piece of white paper placed upon the stage of the microscope, the mirror being moved up and down the rod until the requisite focus is obtained. This focus will, how-

ever, strictly speaking, vary somewhat according to the inclination of the mirror, due to an alteration in the inclination of the microscope or height of the lamp.

The plane mirror should preferably be 'parallel worked,' otherwise an annoying double or treble reflection will be observed when the condenser is in focus. This may be obviated in most mirrors by rotating them in their cells, as suggested by Dr. Dallinger, until a certain point is reached, when all the images are superimposed. All mirrors might with advantage be mounted so as to admit of this rotation. The optical reason given for this duplication of the image is that an ordinary mirror is somewhat wedge-shaped, and there are, accordingly, distinct reflections from the glass surface, from the silver surface, and from the silver and air surfaces. To obviate this, certain workers use a rectangular prism instead of a mirror, but this has the disadvantage of requiring that the prism should be large enough for use with a modern condenser with its wide back lens. It is also, as might be expected, much less convenient to use, and is therefore comparatively seldom met with.

The Sub-Stage.—This is now a most important adjunct to the modern microscope. Its office is to carry the condenser and other apparatus. Without such a fitting no microscope-stand can be considered complete or capable of doing good work with other than low powers. It is the condenser that makes the modern microscope so enormously superior to its predecessors, and it is second only in importance to the invention of the achromatic objective. Its office, as already intimated, is to gather together, concentrate, and focus the light upon the object from beneath. No microscope

should be purchased that has not fittings for such a condenser, or to which the condenser cannot, at any rate, be subsequently readily added. In its simplest form it is merely a ring fitted beneath the stage, and centred with the optic axis of the microscope. The inside diameter of this ring should be of the 'universal' size adopted by the Royal Microscopical Society—*i.e.*, $1\frac{1}{2}$ inches full (1·527 inches, or 38·786 millimetres). The condenser, in a suitable mount, slides up and down in this ring, which is often made to swing aside when not required.

Focussing Sub-Stage.—But as the condenser requires focussing like the objective, a focussing adjustment becomes more than a convenience. This in its cheapest form is provided by means of a left-hand screw and milled head working vertically (Fig. 21, p. 42), which is so arranged as to swing the condenser aside when it is quite out of focus and clear of the stage. But in the best instruments a complete sub-stage with rack and pinion is provided (Fig. 12), and there may even be added an additional fine adjustment to enable the last delicate adjustments to be made without setting up any disturbing tremor. This is, however, a refinement that is only needed for the most critical work. Further, as the centring of objectives generally varies more or less, as already intimated, it is advisable to have some means of centring the condenser, a matter of no little importance in high-power and critical work.

Centring Sub-Stage.—This is provided by two centring screws working at right angles against a spring, or by proper rectangular movements. But whether a simple ring or a complete sub-stage be provided, it should be constructed in a workmanlike manner. There should be no tendency to shake, a weakness to which the swing-

out and spiral-screw forms are somewhat liable, and the centring should remain the same whether the condenser be screwed or racked up or down. A means of rotating the condenser or other fitting by rack and pinion is sometimes provided, but in few cases is this worth the additional cost.

Diaphragm.—The **Diaphragm** is a means of adjusting the light so as to bear some ratio to the apertures of the various objectives. In its simplest form it is a circular plate containing apertures of various sizes, and set just beneath the stage, so that by rotation each of the openings can be brought central with the opening in the stage. The most unsatisfactory form of all is where one or more rings are provided to fit inside the stage opening. But the widespread use of the condenser has necessitated the placing of the diaphragm immediately beneath it, and in this position the plate of diaphragms has given place to a set of loose stops which can be slipped into a suitable carrier, or to the now familiar iris diaphragm.

Condensers themselves are dealt with in Chapter V.

The Limb.—The **Limb** is the arm carrying the body tube, and on its construction much depends. There are practically three forms now in use—that originally designed by Ross, and known as the bar movement, the solid limb, and the Continental limb. They are so closely bound up with the coarse and fine adjustments that we must consider them under these headings.

Coarse Adjustments.—The **Coarse Adjustment** in its simplest form is simply a broad ring in which the body tube slides. It is manifestly only fitted to the least expensive instruments, though when an efficient fine adjustment is provided in addition it is capable of good work up to a certain point. Not the least of its dis-

advantages is, however, the increased danger of damage to either objective or slide, and we consider a thoroughly well-made rack and pinion coarse adjustment, without fine adjustment, often preferable to a sliding coarse adjustment and an additional fine adjustment. W. Watson and Sons have recognised this fact by putting such an instrument upon the market in their ' School ' microscope. Whenever possible, however, and certainly in all stands intended for good work, the coarse adjustment should be by rack and pinion. Many years ago Swift and Sons introduced a ' diagonal ' rack and pinion, which has now been adopted by all the leading makers, which works with exceeding smoothness, and is less sensitive to wear and consequent ' back-lash ' than the older form. Mr. E. M. Nelson has quite recently introduced a ' stepped ' rack and pinion, formed by two racks, one of which is capable of adjustment, but this is, of course, more costly than the ordinary type. The bearings of the coarse adjustment, or the slides in which it works, should be ' sprung,' and provided with screws for adjustment for wear and tear, and there should be ample bearing surface. The milled heads should be large.

Fine Adjustments.—The **Fine Adjustment** brings us to a subject upon which much controversy has taken place. It is scarcely necessary to explain that good work with high powers cannot be done without an efficient fine adjustment, and of all parts of the microscope this is the one that has most tendency to deteriorate and become inefficient. The modest compass and design of this book prevent a full discussion of the various types now in use, and of the improvements and refinements which the ingenuity of various workers has brought forth, but we can explain in detail the main

2

points of the principal types. First of these in point of seniority comes Powell and Lealand's form (Fig. 25). The coarse adjustment is a massive bar working vertically within the casting which supports the stage. To the top of this and at right angles is bolted a bar or arm which projects beyond the centre of the stage, and into which is screwed the body tube. Within this horizontal arm is a lever of nearly the same length, which is raised and depressed by means of a screw fitted with a milled head, and placed just behind the junction of upright bar and arm. The fulcrum of this lever is near the body-tube end of the arm, and within the body tube it moves a nosepiece which carries the objective. As made by Powell and Lealand in their famous but costly stands, this form of coarse and fine adjustment has, as a well-known writer says, 'held an unrivalled position for the past fifty years.' But unless the reader proposes to buy a microscope made by this particular firm, we would strongly urge him to avoid absolutely any instrument in which this model is apparently followed, whether it be new or second-hand. As made and exposed for sale in the windows of the average optician, the coarse adjustment is a mean triangular bar with perhaps one edge converted into a rack-work, and showing distinct lateral play even before use, whilst the fine adjustment is a screw at the side of the body tube working on a bracket, and actuating an ill-fitting short tube within. There are hundreds of such stands for sale in London and the provinces, but they are only sold to the ignorant, and a maker of any present-day reputation would be chary of displaying even a second-hand microscope of this type in his window. The coarse adjustment is untrustworthy from the start, and rapidly becomes worse, whilst the fine adjustment deteriorates even

more quickly. The next form of fine adjustment is that of which the Jackson model may be taken as a type (Fig. 33). Here there is a solid arm projecting over, and firmly bracketed to, the stage. The rack-work of the coarse adjustment is attached to the body tube, and works in **V**-shaped slides. We have already said that these bearings should be of ample length and properly

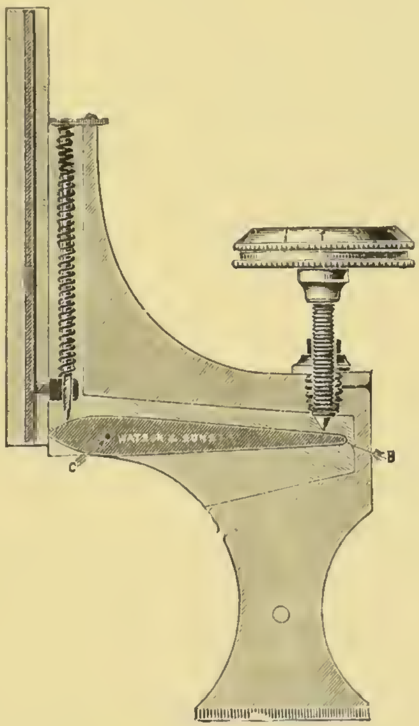

Fig. 7.—Watson's Fine Adjustment.

'sprung.' Between the slides of the coarse adjustment and the limb or arm is a second set of similar **V**-shaped slides forming the movement of the fine adjustment. The body is raised or lowered by means of a lever working against a spring, and actuated by a fine micrometer screw (Fig. 7), much as in the Powell and Lealand form, except that the whole body instead of an inner tube

is moved. This is one of the best forms known ; it is rigid, extremely sensitive, and not liable to deteriorate rapidly even in unskilled or careless hands. In this form also it is apparent that the distance between objective and eyepiece remains unaltered. This fine adjustment is adopted by W. Watson and Sons in nearly all their stands, and by Charles Baker in some of his more recent models; also by James Swift and Son in one or two models, but in the last maker's stand the lever is bent downwards, and the milled head comes at the side, so that it cannot be actuated by either hand. Watson and Sons have also brought out a further refinement of this adjustment designed by Mr. Stringer.

The remaining form of fine adjustment is that represented by the Continental form of direct-acting micrometer screw, which moves the limb as well as the body, the former working generally upon an upright triangular bar. We are sorry to have to admit that this form is perhaps more often met with than any other. It is universal wherever the Continental stand has made its way; its main merit must surely be its cheapness, and we regret that more than one of our leading English makers, who have so often shown the way for Continental makers to follow, have been forced by foreign competition to adopt the cheaper but less efficient design. That it is imperfect is proved by the fact that progressive and well-known Continental firms like Zeiss, Leitz, and Reichert, have found it necessary of late to modify their fine adjustments in order to bring them up to present-day requirements. Briefly put, the drawbacks of this type of fine adjustment are due to the fact that the whole weight of limb, body tube, objectives, etc., is borne on a single direct-acting screw, which if fine soon wears out, and if coarse is insufficiently sensitive.

Moreover, the leverage of the projecting limb accentuates the wear and tear, being assisted therein by the ineradicable tendency of the average student to lift his microscope bodily by this limb. The modifications of this form of fine adjustment already alluded to are a step

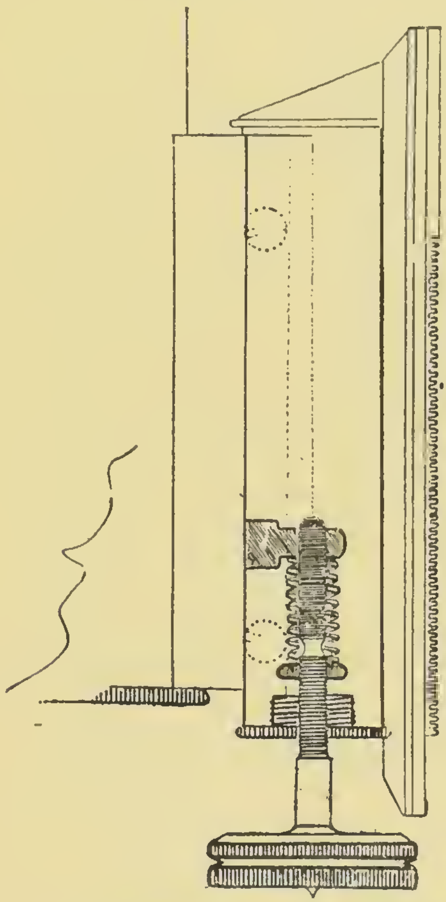

FIG. 8.—CAMPBELL'S FINE ADJUSTMENT.

in the right direction, and we must expressly exempt from much of our criticism the Campbell differential screw adopted by Charles Baker in his beautiful 'Nelson' models (Fig. 8). This is a double screw of different threads, by means of which the actual movement is only

the difference between the threads. Swift's 'Ariston' form has equal merit (Fig. 9). In Zeiss's new form as fitted to their photo-micrographic stands the milled heads project horizontally on each side of the limb, and bear a worm-screw, which rotates the fine adjustment screw by means of a corresponding pinion below the latter, means being adopted to check overrunning. In Reichert's new form, as in Swift's, the motion of the vertical micrometer screw is transmitted to the limb through two short levers bearing one upon the other.*

Before leaving the subject, we may mention that when photo-micrography is in view the milled head of the fine adjustment should be grooved, so as to hold a fine cord. It is of advantage to have the edge of the milled head divided, so that, the movement being known, it may be used to gauge thicknesses, to take refractive indices, etc.

Tube and Tube Length.—The **Body Tube** is the optical tube which carries the objective and eyepiece. Not the least of the benefits which microscopists owe to the Royal Microscopical Society is the standardizing of the screw of the objective, and the 'Society screw' is now almost universally accepted by microscope makers throughout the world, the necessary standard gauges being supplied at cost price by the Society. As a result, 'adapters' to permit of an objective by one

* W. Watson and Sons have very recently brought out a very novel adjustment, which is fitted to their new 'Argus' microscope, more fully explained on p. 42. A single slide serves for both coarse and fine adjustment. The latter is a micrometer screw actuated by a milled head beneath the limb, and in the screw of the fine adjustment the pinion of the coarse adjustment works direct, the screw being supported behind by a sort of fixed pinion, both pinions forming thus the screw-block for the micrometer screw. The idea is commendable for its ingenuity, but one can scarcely say yet whether it will stand the test of severe wear.

maker being used with a microscope by another maker of possibly different nationality have become things of the past. The size of the tube itself, however, and the diameter of the eyepieces have met with less universal acceptance. The diameter of the tube is variable, but preference should be given to one with a fairly large

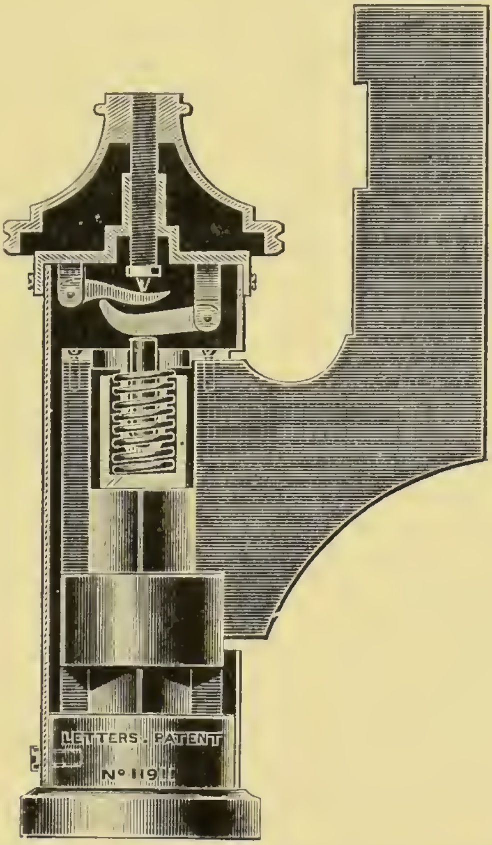

FIG. 9.—'ARISTON' FINE ADJUSTMENT.

diameter, not only on account of the draw-tube, but in consideration of the advantage of a fairly wide tube in photo-micrography. Zeiss, for example, fits a specially wide tube to a microscope intended for this purpose alone. The standard length of the English tube is,

or rather was, 10 inches (250 millimetres), this length being the normal visual distance of a normal eye. The Continental tube is from 6 to 7 inches (160 to 180 millimetres), and the importance of the difference lies in the fact that an objective is necessarily ‘ corrected ’ by its maker for a definite thickness of cover-glass and a definite length of tube. A variation in the thickness of the cover-glass of the object requires a corresponding adjustment in tube-length, according to a practice that will be explained later, unless some means is provided of adjusting the objective itself. The necessity for this correction becomes more marked with high powers. It follows, therefore—and this must be carefully borne in mind—that objectives made or, as it is technically called, ‘ corrected ’ for the one tube-length cannot be used for the highest class of critical work with the other tube-length, though low powers with low eyepieces bear the alteration fairly well. It has been stated that an objective corrected for the long tube performs better on the short tube than an objective corrected for the short tube does on the long tube, and in contra-distinction to this that an objective corrected for the short tube bears high eyepiecing better than one corrected for the long tube, and it is probable that the latter statement at least is correct. Until comparatively recently all English objectives were, however, corrected for the long tube, but of late most of our leading makers have adopted the short tube-length as the standard for their students' series of objectives, owing partly to the increased use of the more compact short-tubed microscope, and to the necessity of conforming to Continental practice born of foreign competition. But the best English and some of the best Continental lenses are still corrected for the longer tube-length ; and to provide

for the use of both kinds of objectives, and to give facilities for the means of correction already alluded to, the body tube is made with an inner **draw-tube,** and sometimes with two such tubes (like a telescope), one of the tubes being perhaps even provided with a rack and pinion for facility in exact adjustment. With the exception of binocular microscopes, and those made by Messrs. Powell and Lealand, which still retain the 10-inch tube-length, all our more modern English stands have body tubes about 6 or $6\frac{1}{2}$ inches long, generally capable of extension to about 10 inches. Some makers provide a wider variation, such as from $5\frac{5}{8}$ inches (142 millimetres) to 12 inches (305 millimetres), and the advantage of this is obvious. The Continental and American microscope does not generally extend sufficiently to enable it to be used with objectives corrected for a 10-inch tube, and this is manifestly a drawback. After what we have said, the necessity of a draw-tube is obvious, and it should be graduated in inches or millimetres, to show the amount of extension and for facility in adjustment. We may mention here that the method of measurement of this tube-length is not clearly defined, measurements being variously taken from the upper end of the tube where the eyepiece is inserted to its lower end containing the screw of the objective, known as the mechanical tube-length, and from the anterior principal point of the ocular to the posterior principal point of the objective (Dallinger), known as the optical tube-length. In practice, however, these measurements need not be gone into too closely, as no practical microscopist would adjust his tube-length or objective to make the necessary corrections by any other guide than his estimation of the image under inspection at the moment.

In the binocular microscope the tube is necessarily of

a fixed length, some slight adjustment being provided only for the varying distance between the eyes of different observers.

The lower end of the draw-tube should be provided with the Society screw, so as to permit of the insertion of objectives having an exceptionally long focus, or of lenses constructed for special purposes, such as the Bertrand lens, or of the lens provided with Zeiss's apertometer.

Diameter of Draw-Tube.—The upper end of the draw-tube contains the eyepiece, which should fit easily, so as to cause no danger of forcing down the tube and objective upon the slide beneath. The diameter of the eyepieces, as already intimated, is not uniform, the Continental size, now adopted in most of our own students' microscopes, being the smallest, whilst the English eyepiece is considerably larger. To endeavour to minimize this state of things, and at the same time to formulate a scheme that would bring all the principal opticians into line, the Royal Microscopical Society has quite recently definitely adopted four standard sizes for eyepieces. These are as follows: No. I., 0·9173 inch (23·3 millimetres); No. II., 1·04 inches (26·416 millimetres); No. III., 1·27 inches (32·258 millimetres); No. IV., 1·41 inches (35·814 millimetres). Of these, No. I is the size in general use on the Continent, and has been adopted by several English makers for their students' size instruments; No. II. is the mean of the sizes used by the English makers, and is apparently meant to meet the objections of those makers who have hitherto clung tenaciously to their own originally adopted size; No. III. is the new size adopted for the larger English stands, especially binoculars; whilst No. IV. is, we believe, used in Powell and Lealand's and

one of Beck's stands only. There can be little doubt that the interests of microscopists generally would be best served by the adoption of Nos. I. and III. only, and it is worthy of note, as an evidence of public spirit, that immediately on the publication of these standards two of our leading makers, Charles Baker and W. Watson and Sons, promptly adopted these two standards, though this necessitated the changing of their gauges, sizes of tubes, etc. There can be no question that the No. III. size, which may be taken as the English size, is preferable to the No. I. or Continental size. This latter is smaller than is necessary, and has consequently certain disadvantages attending it, though it must be admitted that few objectives will bear an eyepiece whose width, when uncurtailed by a diaphragm, utilizes the extreme peripheral rays of the objective.

CHAPTER III

THE CHOICE OF A MICROSCOPE

Having endeavoured to explain as fully as possible the principles of design in the modern microscope stand, it will be advisable to give a practical demonstration of our remarks by rapidly passing in review some of the stands of various leading makers, with a view to assisting in the choice of an instrument. It is, of course, impossible to mention every microscope upon the market, but though the omission of any particular instrument by no means implies its inferiority, yet it is a noticeable fact that those instruments which are especially distinguished by excellence of design and workmanship are made by a comparatively small group of makers, perhaps some half-dozen or so in England, four or five on the Continent, and two or three in America. These makers are constantly striving to perfect their instruments, both mechanically and in their optical parts, and deserve special notice accordingly. We are therefore doing no injustice to others, as matters stand at present, in advising the prospective purchaser of a microscope to confine his choice to well-recognised makers, *to buy no instrument that does not bear a name upon it*, and in particular to be cautious in deciding to buy any instrument without a most careful consideration of its real value. There are many microscopes offered for sale

by firms of repute in other branches of optical and scientific manufacture that are quite unworthy of the name of microscope, as the term is understood by serious workers with this instrument, and of which but a little experience is needed to show the inferiority to the best instruments of their class, types of which we are about to deal with specifically. The reader who has carefully perused the preceding chapter will be in a position to understand the terms used in describing a microscope, and will appreciate for himself the advantages of the respective instruments; but as a microscope is by no means an inexpensive instrument, and the purse may not necessarily be a deep one, it may be as well if we give here the table of relative importance of the various parts which appears in Carpenter's 'The Microscope and its Revelations,' as drawn up by Dr. Dallinger.

Relative Importance of Microscope Parts.

1. A coarse adjustment by rack and pinion.
2. A sub-stage.
3. A fine adjustment.
4. Mechanical movements to sub-stage—*i.e.*, focussing and centring.
5. Mechanical stage.
6. Rack-work to draw-tube.
7. Finder to stage.
8. Plain rotary stage.
9. Graduation and rack-work to rotary stage.
10. Fine adjustment to sub-stage.
11. Rotary sub-stage.
12. Centring to rotary stage.

Few workers will wish to materially alter the order in which these stand, unless, perhaps, to put No. 6 rather lower down in the list, or to insert the provision

of a sliding-bar to the stage as an alternative before No. 5. The order of Nos. 11 and 12 might also possibly be reversed.

Simplest Form of Microscope.—Our simplest microscope is, then, a microscope with a plain stage, mirror, and coarse adjustment by rack and pinion. Such a

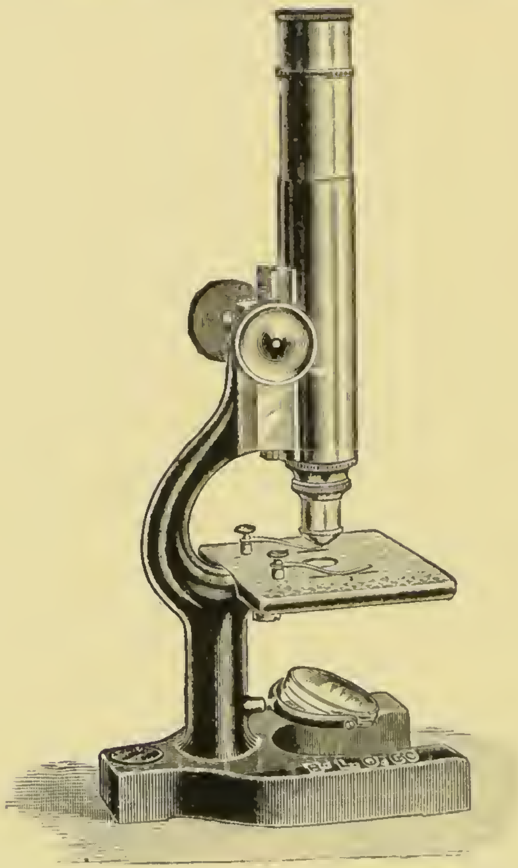

FIG. 10.—BAUSCH AND LOMB'S MICROSCOPE (CHEAP FORM).

microscope is made by Leitz and by the Bausch and Lomb Optical Co. for the extraordinary sum of £1, the last-mentioned stand being beautifully finished (Fig. 10). As a laboratory microscope for rough work such an instrument is a most useful possession, and it is capable of good work of other kinds up to a certain

degree, for there is no question that a good and well-made coarse adjustment is a more satisfactory matter than an ill-designed fine adjustment. Recognising this, W. Watson and Sons make a still better instrument of this type for school use at a rather higher price, as already mentioned.

The next type is naturally a microscope similar to the foregoing, but with a fine adjustment and a sliding-tube

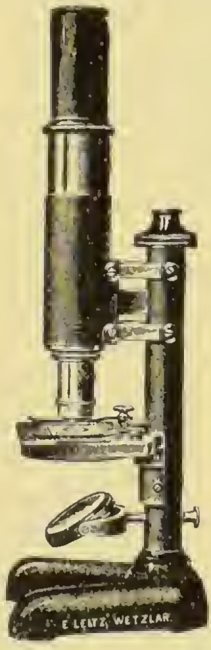

FIG. 11.—LEITZ'S MICROSCOPE (SLIDING TUBE).

coarse adjustment. Microscopes of this kind are made by all the Continental and American makers, and by R. and J. Beck in England. Fig. 11 represents Leitz's form. They are in common use in our medical schools and elementary science laboratories, and the best that can be said in their favour is that they are cheap, and that the perfunctory way in which the use of the microscope as a microscope is taught in such laboratories

renders it inadvisable to hand over anything better to the tender mercies of those who use them. We have observed that under such circumstances the fine adjustment is nearly always used to focus the low as well as the high powers, and it is small wonder that the screw of the fine adjustment soon shows marked evidence of such use. This may be an argument against providing better instruments, but it seems to us rather an argument for providing more information as to the use of the microscope, which is still too often looked upon as a mere magnifying-glass.

Students' Microscopes.—In microscopes fitted with both coarse and fine adjustments, together with a substage, we have a large choice. Dealing with the less expensive stands first, and taking the leading English makers in alphabetical order, we have Charles Baker's 'D.P.H. No. 2' microscope, illustrated in Fig. 12. The foot is of the 'claw' type, which is very nearly as steady as the tripod, and gives more room beneath the stage. The fine adjustment is of the sensitive lever type, with solid limb bracketed to the stage. There are two draw-tubes in a body 1½ inches in diameter, giving a variation in tube-length from 6 to 10 inches, and the stage has a sliding-bar with vertical and horizontal graduations for use as a finder. The opening in the stage is cut out in the front as suggested by Mr. E. M. Nelson. There is a centring and focussing sub-stage. The same microscope is also supplied with mechanical stage.

A somewhat similar microscope is the 'R.M.S. 1·27,' which has eyepieces of the 'R.M.S. No. 3' gauge, rack-work to the draw-tubes, and partial rotation to the stage.

The latter description applies generally to the same

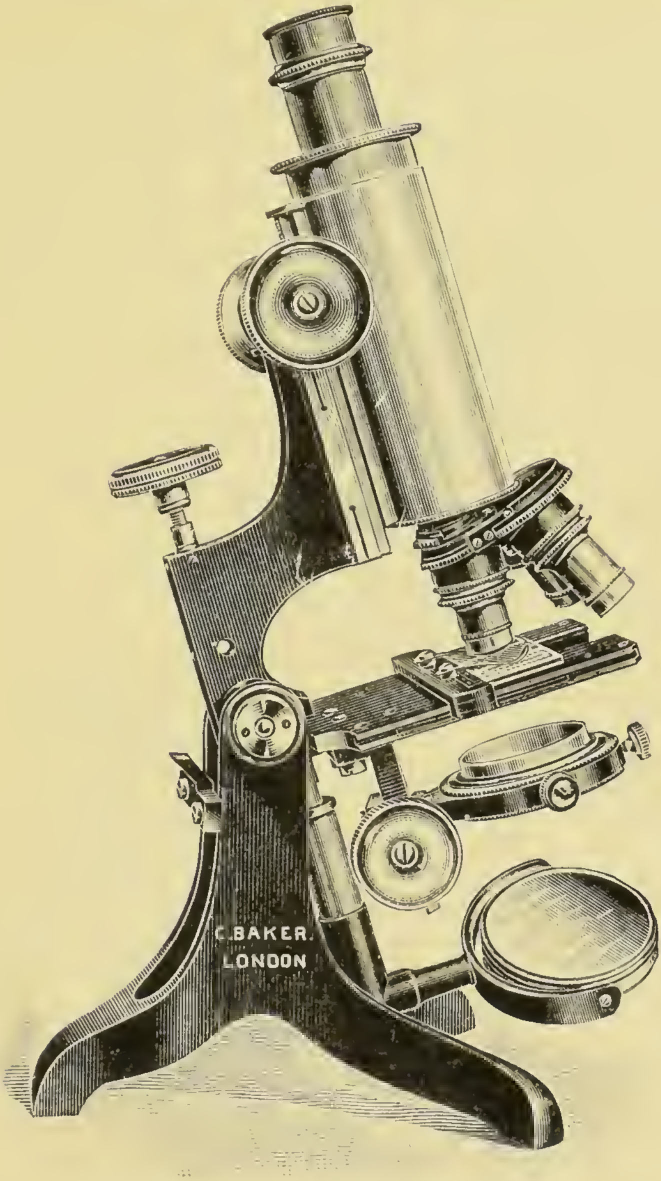

FIG. 12.—BAKER'S 'D.P.H. No. 2' MICROSCOPE.

firm's 'Nelson Model No. 2,' designed by Mr. Nelson, and illustrated in Fig. 13. It will be noted that the stand is a true tripod, with slotted toes for attachment

in photo-micrography. The fine adjustment is by Campbell's differential screw, which has been already described. The mechanical stage is divided on brass, and the stage is capable of rotation for about 300 degrees.

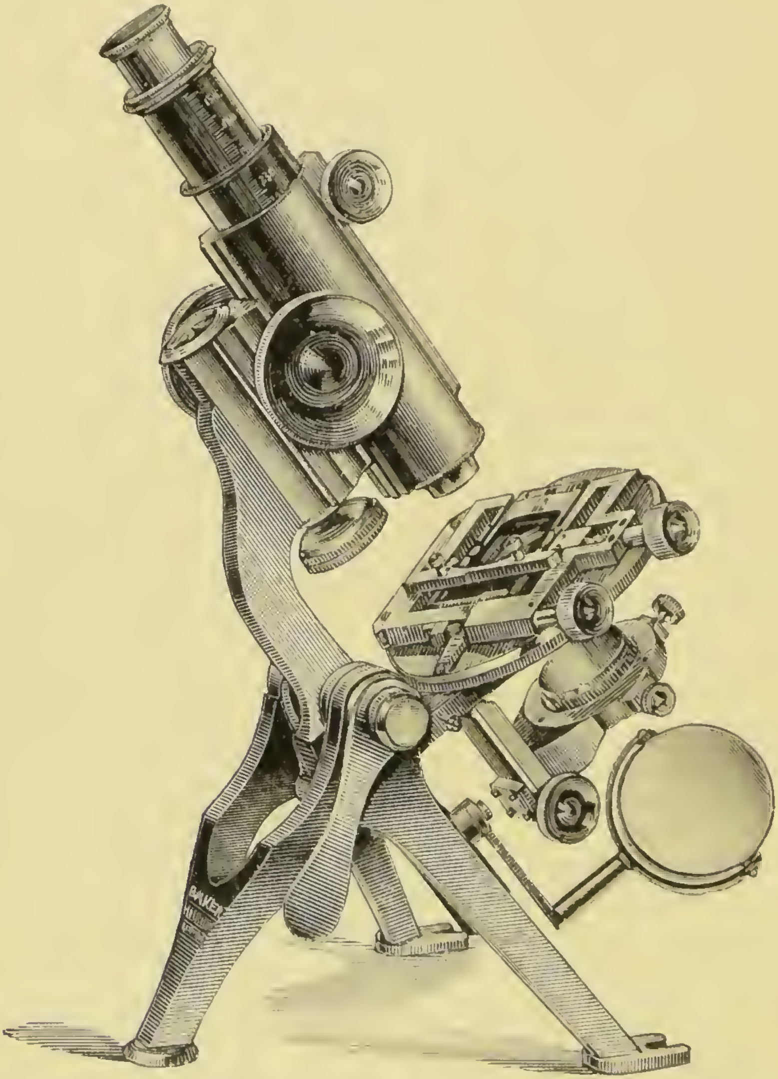

FIG. 13.—BAKER'S 'NELSON MODEL NO. 2' MICROSCOPE.

All these microscopes are of excellent workmanship and design, and fitted for almost any kind of work.

R. and J. Beck's most notable microscope of this

class is their new 'London' stand. The design is of the Continental type, as the makers recognise the hold this kind of microscope has in our medical schools and university laboratories. The criticisms levelled at the horseshoe foot and at the triangular bar and micrometer screw fine adjustment, carrying both limb and body tube, apply, therefore, to this model, but our criticism

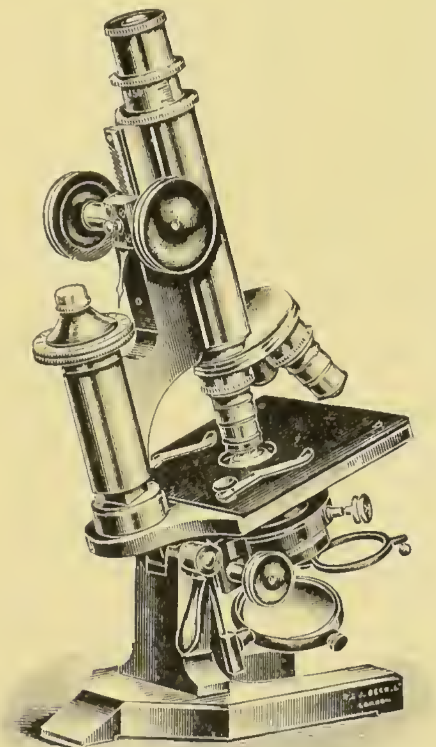

FIG. 14.—BECK'S 'LONDON' MICROSCOPE.

need go no further than this. The workmanship is good, and the price extraordinarily low, whilst by bringing the pillar forward and placing the inclining joint immediately beneath the stage greater stability is given to the whole stand in various positions. This microscope is made in various degrees of completeness,

from a plain stand with coarse and fine adjustment, without sub-stage, costing, without lenses or eyepieces, £2 13s. only, to a larger model with removable mechanical stage and compound sub-stage. Perhaps the last, with the mechanical stage removed (Fig. 14), may serve as illustration. The stage is ebonite, 4 inches square, there is a clamp to the joint for inclination, and the

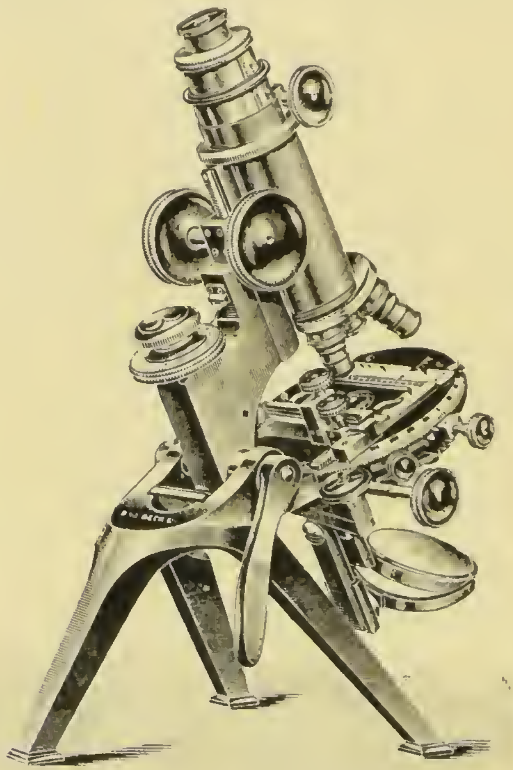

FIG. 15.—BECK'S 'IMPERIAL' MICROSCOPE.

large milled head of the fine adjustment as well as the draw-tube, which extends from 140 to 200 millimetres, is graduated.

The same makers' 'Imperial' microscope is fitted with lever fine adjustment, rackwork to draw-tube, and compound sub-stage. It is a full-size model, and almost

any of the refinements already dealt with can be fitted to this instrument (Fig. 15), as shown.

Ross's 'Standard' microscope is of very similar pattern, and is made in two sizes. The smaller size

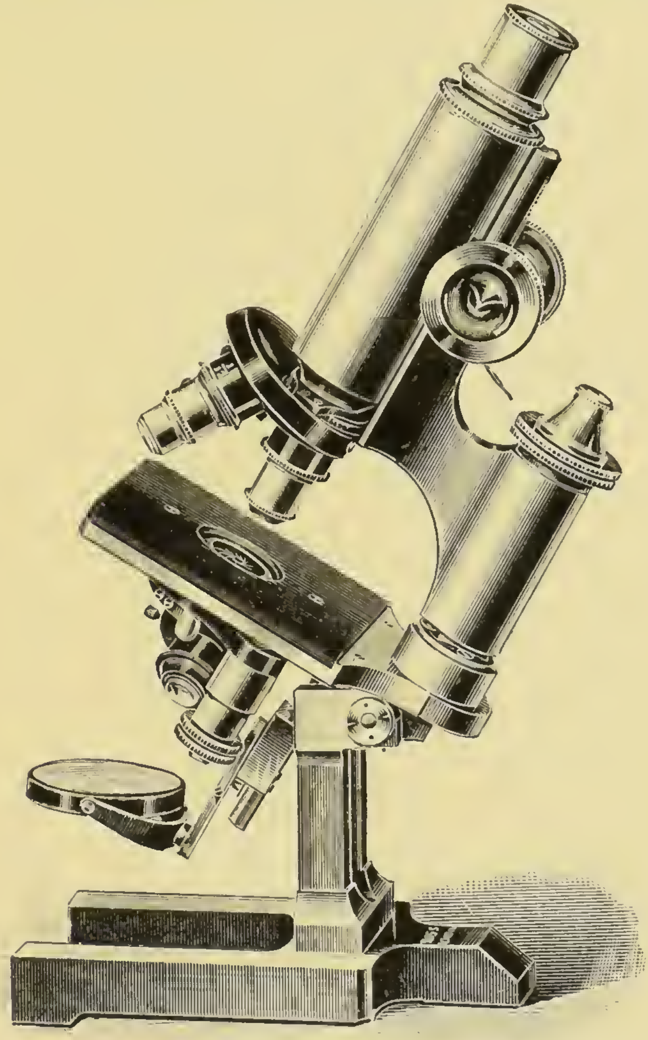

FIG. 16.—ROSS'S 'STANDARD NO. 2' MICROSCOPE.

(Fig. 16) has inclining limb, coarse adjustment by rack and pinion, and fine adjustment by direct-acting micrometer screw, a $3\frac{1}{2}$-inch square metal stage, with

diaphragm beneath, and draw-tube extending to 160 millimetres only. The larger size, which we illustrate (Fig. 17), has a rotary centring stage with detachable

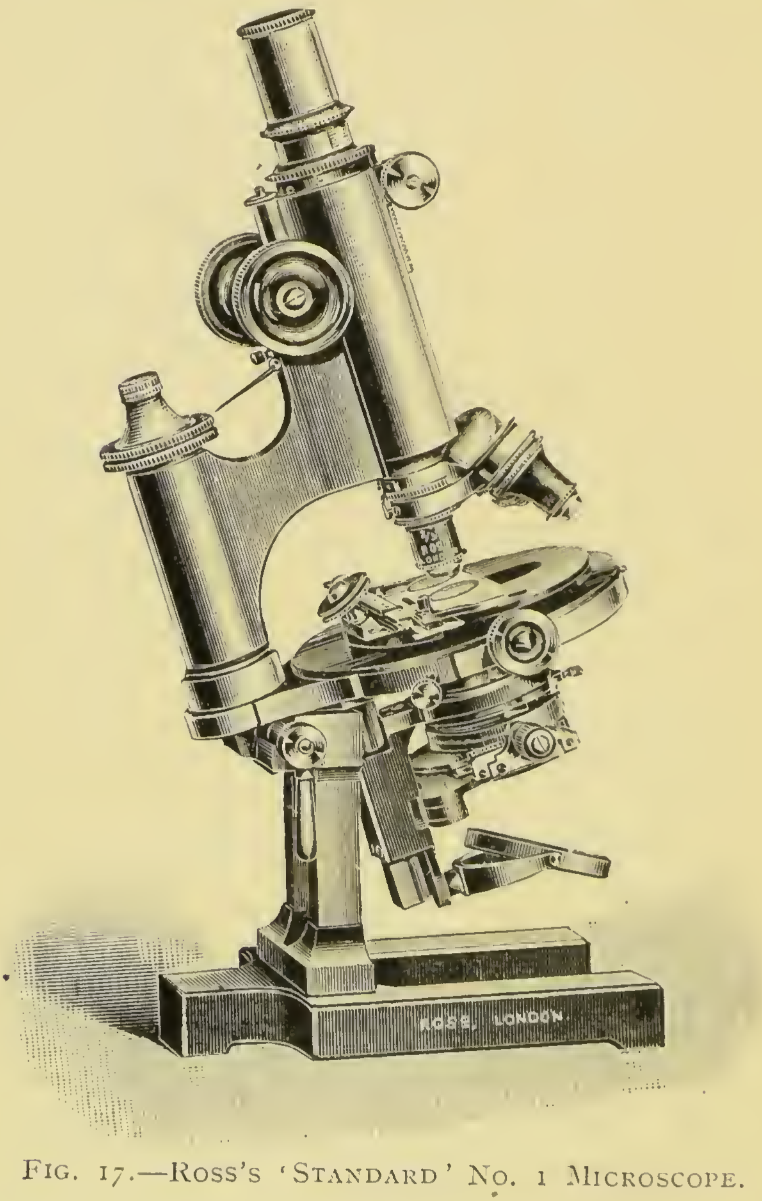

FIG. 17.—ROSS'S 'STANDARD' NO. 1 MICROSCOPE.

mechanical adjustments, rack and pinion focussing and centring sub-stage with swing-down condenser and swing-

out iris diaphragm, adjustable laterally by rack and pinion, and rackwork to draw-tube.

J. Swift and Son make several types of microscopes, suitable for histology, physiology, bacteriology, etc., of which their 'Bacteriological' microscope (Fig. 18) may

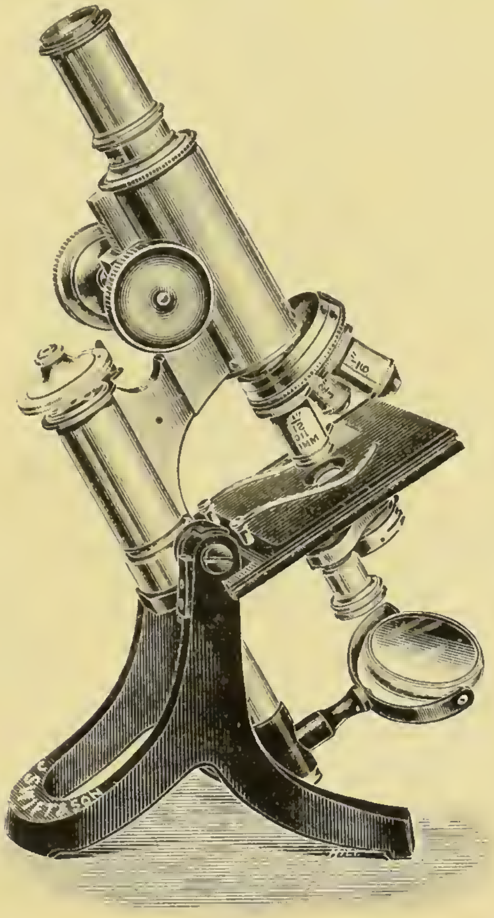

FIG. 18.—SWIFT'S 'BACTERIOLOGICAL' MICROSCOPE.

be taken as an example. The foot is of the convenient Jackson type, the coarse adjustment is by spiral rack and pinion, and the fine adjustment by micrometer screw. The stage is covered with vulcanite, and is specially large, with the right-hand side divided into

squares to serve as a finder. A non-centring ring beneath the stage carries the condenser, and is adjustable by means of a spiral screw, which also serves to swing the condenser out of the field of view if required. The body is of large diameter for photo-micrography with

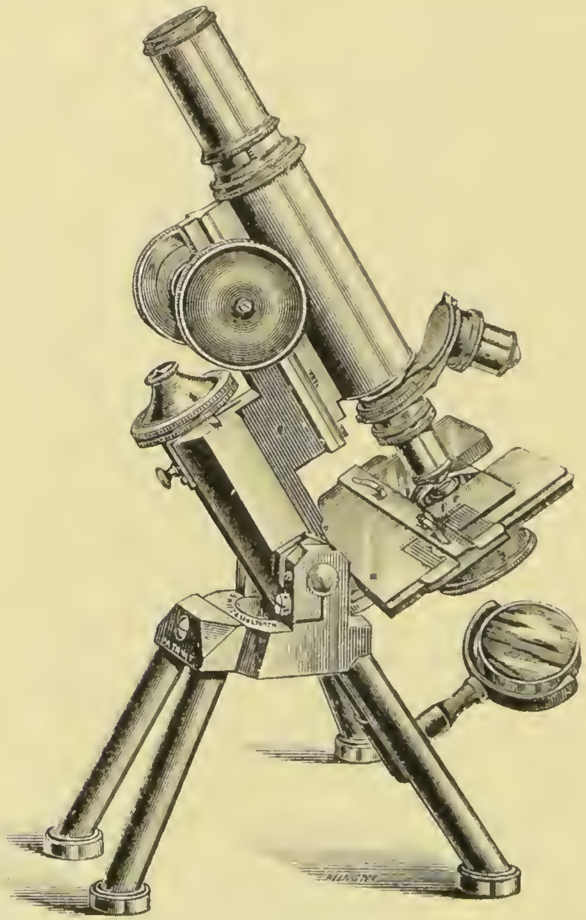

FIG. 19.—SWIFT'S FOUR-LEGGED MICROSCOPE.

low powers, and the draw-tube is graduated and extends from 160 to 220 millimetres.

A microscope somewhat similar in design is fitted with mechanical stage and focussing and centring sub-stage.

Messrs. Swift make also a similar microscope on a true

tripod, but their most notable stand is their four-legged microscope (Fig. 19). The two back legs swing on a pivot, so that they can adjust themselves to any uneven surface, and thus act as a true tripod. The pivot is

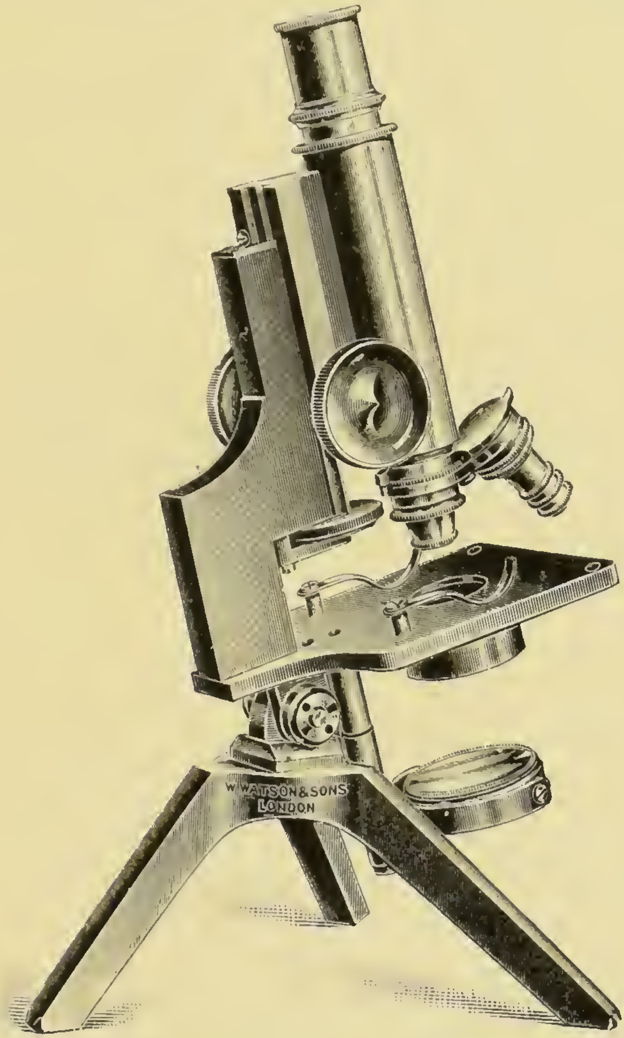

FIG. 20.—WATSON'S 'ARGUS' MICROSCOPE.

compensated for wear, and the two back legs, though perfectly rigid, are reversible, so that the microscope takes up 2 inches less room in its case than the ordinary

tripod. This is quite the steadiest microscope made. The stage has finder lines engraved on it, and can be fitted with a very handy sliding-bar running on rollers in parallel grooves at the sides.

The microscopes of these makers are of excellent workmanship in every way.

W. Watson and Sons have three types of instruments which come under the description of students' microscopes. Their latest pattern is also their cheapest, and is known as the 'Argus' microscope (Fig. 20). It has a short tripod, with joint for inclination, a stage $3\frac{1}{2}$ inches

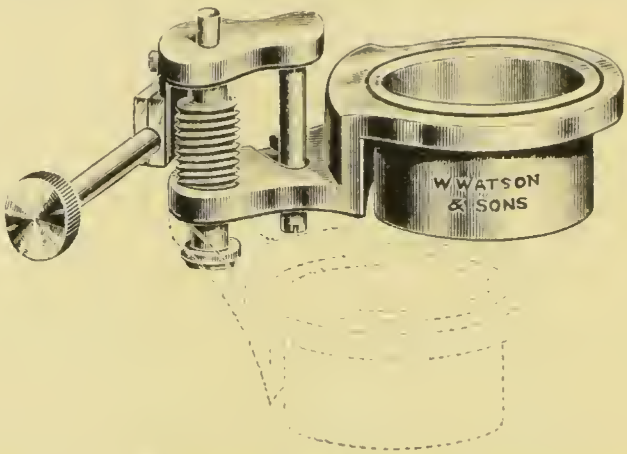

FIG. 21.—WATSON'S NEW SPIRAL SUB-STAGE.

square, with ring beneath for condenser, and a draw-tube extending from $5\frac{1}{2}$ to 9 inches. The limb is bracketed firmly to the stage. The most novel point is, however, the arrangement for coarse and fine adjustment, which has been already mentioned. One slide serves for both. The fine adjustment is a direct-acting micrometer actuated by a milled head placed *beneath* the limb. In this screw the helical pinion of the coarse adjustment engages directly, support being given by a further loose pinion placed on the other side of this screw. Thus the two pinions of the coarse adjustment serve as the block

in which the screw of the fine adjustment engages, whilst the screw in turn replaces the usual diagonal rack. The idea is unquestionably original, and the makers are confident that the arrangement will stand the test of wear and tear. The price of the stand is extraordinarily low—*i.e.*, £2 15s., without eyepieces or objectives.

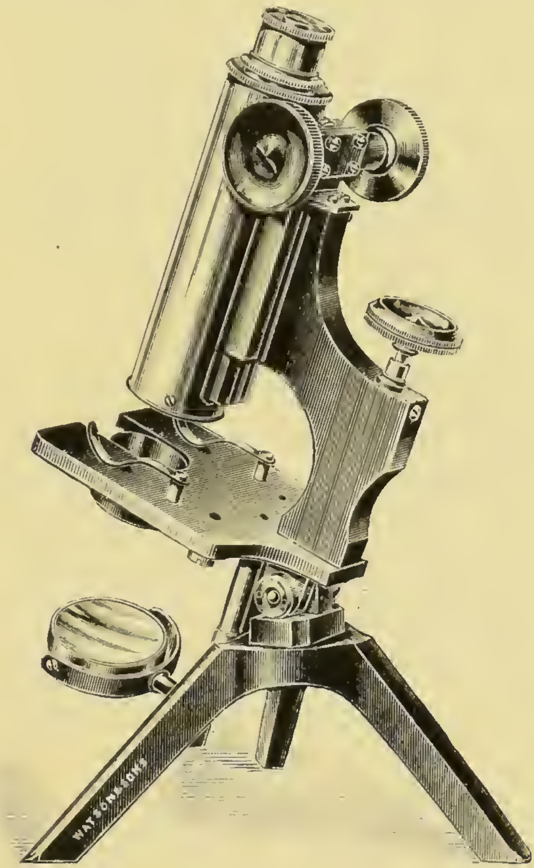

FIG. 22.—WATSON'S 'FRAM' MICROSCOPE.

To this microscope a new pattern sub-stage can be fitted (Fig. 21), designed to retain the advantages of the ordinary spiral screw focussing and swing-out sub-stage, whilst overcoming the want of rigidity which has rendered the latter somewhat unsatisfactory.

The next type of microscope of this enterprising firm is the 'Fram' (Fig. 22). The design is evident from the illustration, but it is worth noting that, though the stand is a low-priced one, the workmanship is of the highest class. The same microscope is also fitted with mechanical stage and compound sub-stage.

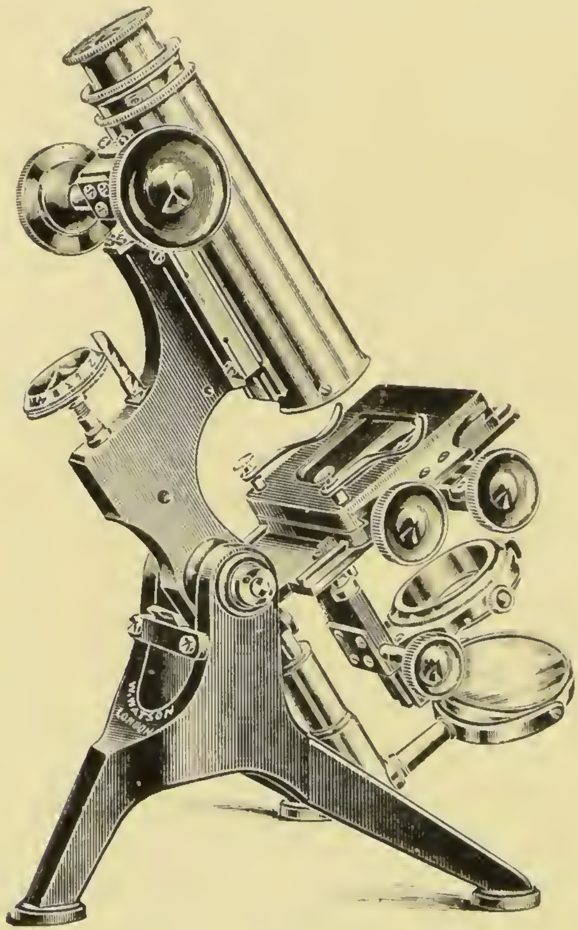

FIG. 23.—WATSON'S 'EDINBURGH H' MICROSCOPE.

This firm's best-known stand is, however, without doubt their 'Edinburgh Student's' microscope, which for excellence of design and workmanship, combined with moderate cost, fully deserves the wide recognition

it has gained. It is made with both horseshoe and tripod foot, and with plain stage with ring beneath for condenser, up to the elaborate form illustrated in Fig. 23. This last is the 'H' model, the graceful appearance of which is at once apparent. The fine

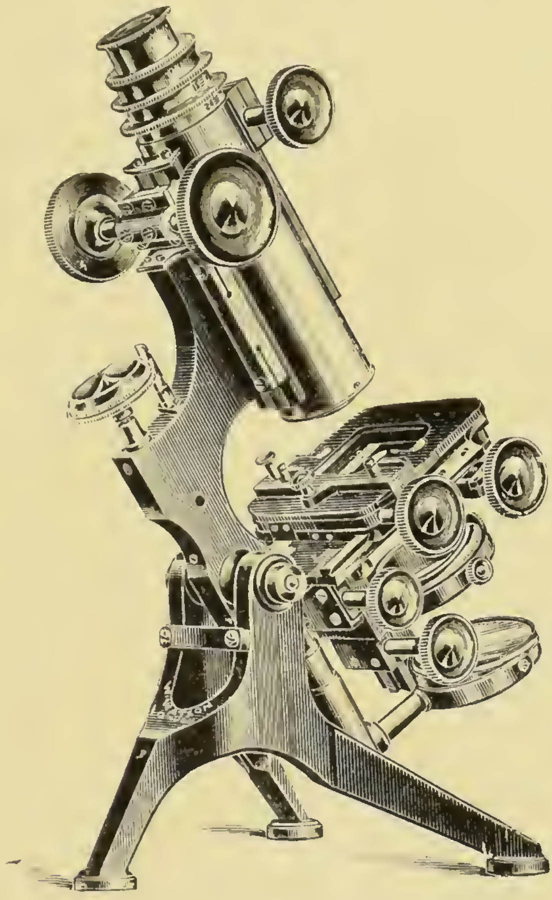

FIG. 24.—WATSON'S 'ROYAL' MICROSCOPE.

adjustment is of the now well-known lever form, which is sensitive to the $\frac{1}{30000}$ of an inch. The milled head is graduated. The draw-tube is also graduated, and extends from $6\frac{1}{2}$ to 10 inches, the body being $1\frac{1}{2}$ inches in diameter. The stage is $3\frac{1}{2}$ inches square,

with mechanical stage and rotating top-plate. There is a compound rack-work (focussing and centring) sub-stage.

Not the least of the advantages of this microscope is the facility with which various further refinements can be added without overburdening it or raising the price to a prohibitive figure. These refinements include a second draw-tube giving larger variation of tube-length, and actuated by rack and pinion, a sliding-bar to the stage with movable stop, graduations to the mechanical stage with verniers to read up to $\frac{1}{10}$ millimetre, and a fine adjustment to the sub-stage. A concentric rotating stage can also be fitted, or the new 'Scop' mechanical stage with milled heads working on a common centre placed diagonally to the stage. These further refinements really constitute a new type of microscope, and one capable of the very highest research work, so that Messrs. Watson have rechristened this elaborated stand as the 'Royal' microscope (Fig. 24).

The examples given will show the variety of design in the students' class of microscope, and that in their most elaborate form they approach closely to the very highest type.

Research Microscopes.—But those who desire and can afford to pay for the very best microscope that can be obtained will find it in such instruments as Baker's 'Nelson' model, Beck's 'Imperial,' Powell and Lealand's famous stand illustrated in Fig. 25, Swift's 'Challenge,' or W. Watson and Sons' 'Van Heurck.' Powell and Lealand's microscope, in particular, has for many years held an acknowledged position amongst microscopes of the very highest class, both for design and for workmanship, and the only criticisms that can be made are against its weight, and that its large size renders it

inconvenient to use at an ordinary table, except in the inclined position. It is noteworthy that this stand has for years remained almost unaltered, whilst all other instruments were undergoing transition, a striking proof of

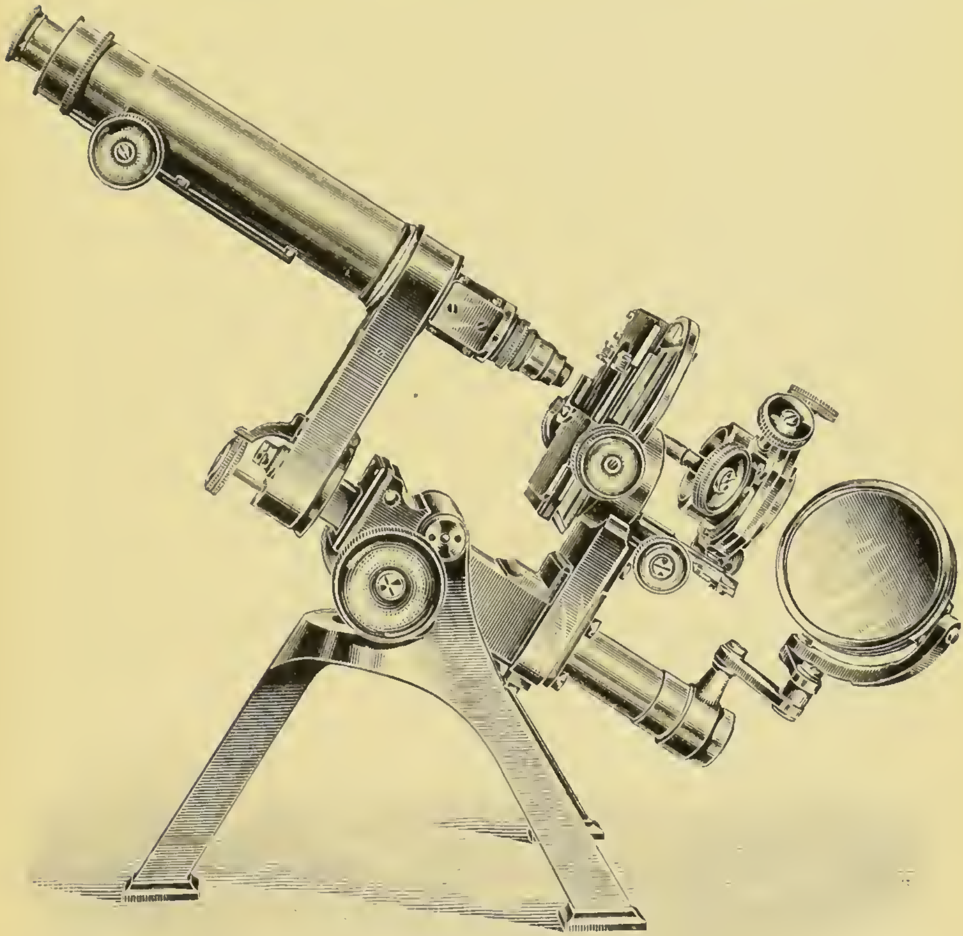

FIG. 25.—POWELL AND LEALAND'S LARGE MICROSCOPE.

the excellence of the design and of the sound judgment, so much in advance of the times, of the designers.

Continental Microscopes.—Our notices of modern microscopes have been confined to a few of the leading

makers, for reasons already stated, but our review would be incomplete if we confined ourselves entirely to English stands, if only on account of the large sale in this country of certain Continental microscopes. The causes of the popularity of such microscopes in our medical laboratories in particular are not quite easy to state. We should be inclined to suggest that, whilst there can be no doubt that the majority of improvements in microscope stands have unquestionably emanated and still emanate from England, our makers have in the past confined themselves too much to making costly stands, fitted with elaborate refinements, and requiring considerable knowledge for their utilization, and have devoted but little attention to the requirements of the ordinary worker or student, who uses his microscope with but little appreciation of its higher possibilities, and to whom the consideration of cost is a very serious item. The result has been a large demand for an inexpensive but well-made stand, provided very frequently with neither condenser, coarse adjustment, nor means of inclination. That the best-known Continental makers are more and more following an English lead in the improvements they are adopting to their microscopes is perhaps evidence not only of a fuller realization of the superiority of the English model, but implies also that our manufacturers in turn are now fully alive to the state of affairs, and rapidly recovering lost ground. We are quite unbiassed in our insistence on the superiority of the English microscope over its foreign competitor, and, indeed, but endorse other and more weighty statements of the same nature. We strongly recommend the purchase of an English microscope, therefore, in preference to one of Continental manufacture, though it will be seen later, when we come to speak of objectives,

that our present criticisms do not apply to Continental objectives.

The best-known Continental makers are Ernst Leitz of Wetzlar, Carl Reichert of Vienna, and the famous firm of Carl Zeiss of Jena, to which we might add Messrs. W. and H. Seibert, also of Wetzlar. Amongst American firms the Bausch and Lomb Optical Co. are well known in England.

We need not describe in detail the various models of these houses, as the examples we have given of other instruments will be sufficient guide as to the requirements of a modern microscope. The distinctive features of the Continental stands, which differ only in detail from each other, are that the foot is of the horseshoe type, the instability of which is in certain cases somewhat reduced by bringing the stand further forward beneath the stage, and the fine adjustment is ordinarily of the direct-acting micrometer screw type, moving the whole limb upon a triangular bar, the disadvantages of which we have already pointed out. We may repeat that of late the Continental makers have shown their recognition of these disadvantages by designing improved forms of micrometer screws, which minimize, if they do not entirely do away with, the drawbacks inherent in this form of fine adjustment. We have already mentioned the very slow and sensitive form of fine adjustment added by Carl Zeiss to his photo-micrographic stand. The eyepieces are in all cases of the Continental size—*i.e.*, 0·9173 inch—but the draw-tube is generally of insufficient extension to enable other objectives to be used than those corrected for the short Continental tube. In the larger stands a most elaborate form of sub-stage is provided. It is focussed by rack and pinion, but the focussing adjustment not infrequently

4

carries also the tail-rod of the mirrors, and moves them at the same time—a manifest disadvantage. A small iris diaphragm is provided *above* the condenser and immediately beneath the stage, which is to be used only when the condenser is removed, and to make the exchange the more readily the condenser itself is mounted on a hinge at one side, so that it can be lowered from the fitting and swung out of the way and upside down. Beneath the condenser when in use is a larger iris diaphragm, which can not only be swung completely aside, but is capable of adjustment horizontally by means of a special rack and pinion, with a view to giving oblique illumination when requisite. This arrangement, though comparatively a recent development, has been adopted by most makers of the Continental form of instrument, but it is, in our opinion, an unnecessary complication (see Chapter V., p. 85).

Choice of a Microscope.—From the types of microscopes just described, and which conform to present-day requirements, the reader can be left to make his own selection, or from their careful study he will have learnt what to look for in stands by other makers. Of course, money at first cost may be saved by buying, for instance, a microscope without a condenser, as in the pretentious stands one meets with in so many opticians' windows, but it is to save the beginner from the mistake of making such a purchase that this part of the present book has been mainly written. We have before said, and it cannot be too often repeated, that a condenser is absolutely necessary if the fine objectives of the present day are to be taken full advantage of, and high-power objectives such as $\frac{1}{12}$ or $\frac{1}{8}$ inch could scarcely be used alone. Sooner or later, therefore, the condenser fittings become a necessity.

The Binocular Microscope.—Keeping in view also the acquirement of a stand which can be used for serious practical work, we have dealt only with the monocular, and not the binocular stand, which, convenient as it is in many ways, and beautiful as are the images which it gives with low powers, has drawbacks which make it unsuitable for general use. These drawbacks are mainly that it has necessarily a fixed tube-length, adjustable only within narrow limits for variation of the width between the eyes of different observers, and that it can only be used as a binocular with objectives up to about $\frac{1}{2}$-inch focus, or, say, 40 degrees air-angle, without great loss of light. Various types of prisms have been constructed for use with high powers, one of which is designed as an eyepiece for use with the ordinary monocular tube, but none of them are thoroughly satisfactory, and in all of them the loss of light and deterioration of the image is very apparent when high powers are used. The Wenham type of prism is generally arranged for withdrawal, in which case the microscope becomes a monocular, but with practically fixed tube-length. In consequence, the binocular is now little met with outside this country, though it certainly has its uses. With low powers the images it gives are strikingly beautiful, owing to their stereoscopic effect, and this latter gives a peculiar depth of vision that is not infrequently of real service to the microscopist by enabling him to realize the contours of minute objects, especially opaque ones, and in grasping the relations of parts in transparent objects in a way that the most careful focussing with the monocular can do only with difficulty. We will content ourselves, therefore, with mentioning that most of the stands described can be obtained with a binocular body

if so required, and that for those who can afford it the addition of a spare binocular body, to replace the monocular and to work in the same fittings, would be

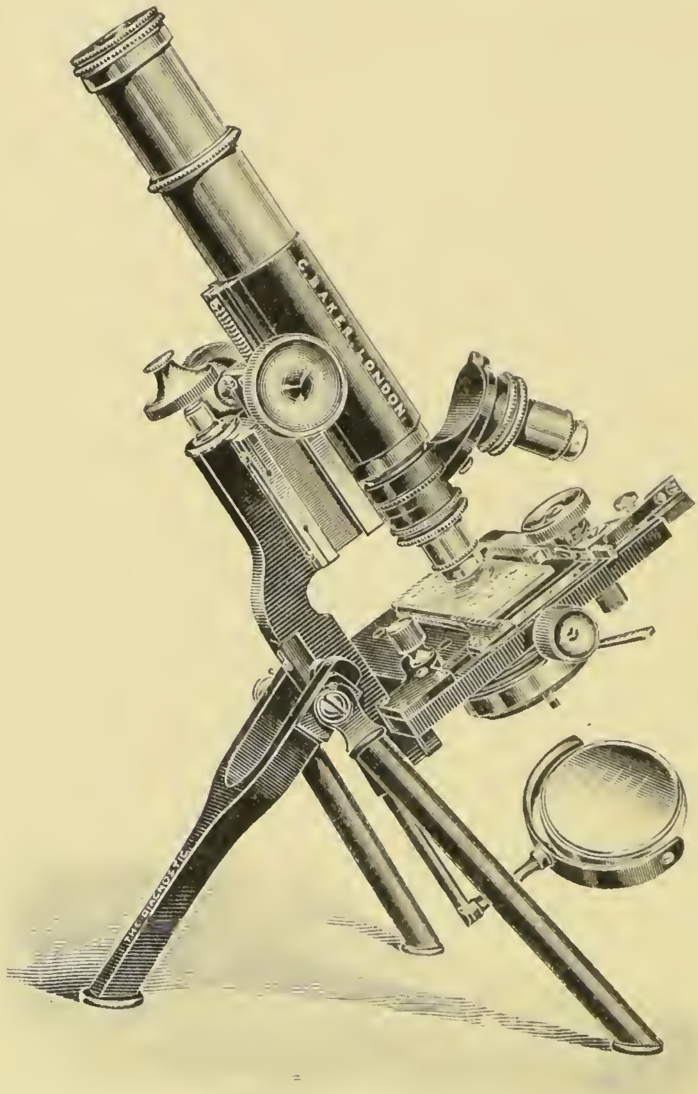

FIG. 26.—BAKER'S 'DIAGNOSTIC' FOLDING MICROSCOPE.

an advantageous addition to the microscopical outfit. One or two special forms of binocular microscope will be mentioned in dealing with microscopes for special purposes, without which our review would be incomplete.

Portable Microscopes.—Of such special microscopes, first, in point of importance, come folding or travelling microscopes. Until quite recently these were for the most part defective in design. Powell and Lealand's portable microscope certainly deserves no such reproach, but it is, perhaps, unnecessarily elaborate. It is similar to their No. 3 stand, but the tripod folds up, and the whole packs into a box $10\frac{1}{2} \times 7\frac{1}{2} \times 3$ inches. The cost is, unfortunately, high—*i.e.*, £24 16s. without objectives.

Charles Baker makes an excellent travelling microscope called the 'Diagnostic.' It was originally designed for Major Ronald Ross for the study of malarial fever parasites (Fig. 26). It stands on a tripod with a spread of 7 inches, is fitted with rack and pinion coarse and direct-acting micrometer screw fine adjustment, whilst the main tube works also in a sleeve to give further latitude for adjustment. There is a draw-tube extending to 170 millimetres ($6\frac{3}{4}$ inches), taking eyepieces of 'R.M.S. No. 1' gauge, square stage with clip, sub-stage ring for condenser, and the usual plane and concave mirrors. The whole packs into a neat leather case, with straps, which measures only $10\frac{1}{2} \times 3\frac{1}{2} \times 3$ inches, and contains in addition two bottles for stains, a bottle for immersion oil, and space for three objectives and an extra eyepiece. The price, complete in leather case without optical parts, is only £3 17s. 6d. A small condenser with iris diaphragm is provided for and can be added, also a specially designed mechanical stage. The exceeding compactness of this stand necessitates, however, a rather small stage, not quite $2\frac{1}{2}$ inches wide.

R. and J. Beck have quite recently arranged their new 'London' microscope as a portable model. The back projecting leg of the horseshoe base slides in, and the side legs fold up, whilst the stage is removable, the whole then packing into a leather case $9\frac{1}{2} \times 4\frac{1}{2} \times 2\frac{1}{4}$ inches,

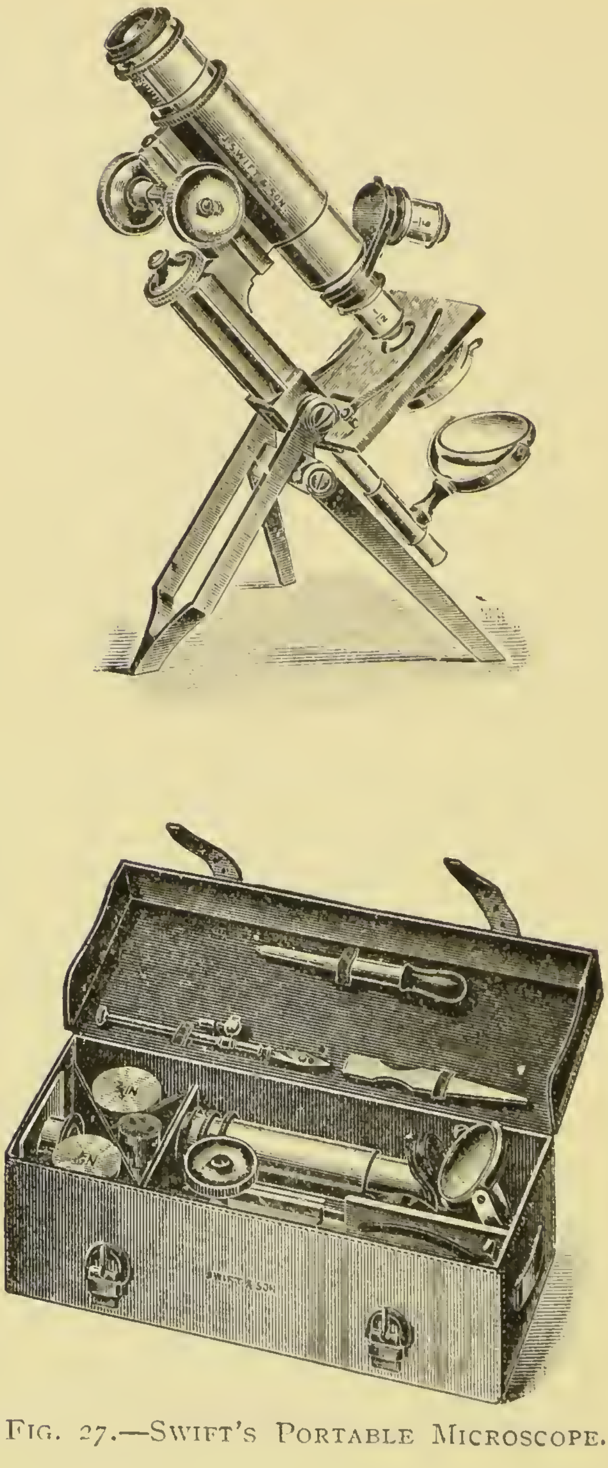

FIG. 27.—SWIFT'S PORTABLE MICROSCOPE.

together with three objectives and two eyepieces. Messrs. Beck make also a small folding microscope of the Continental type, the base of which is hinged, and thus folds together, whilst the stage rotates so as to lie parallel with the body. There is a micrometer screw fine adjustment, but the body tube slides in a ring to form the coarse adjustment. A draw-tube is provided, but no sub-stage. It packs, however, into a case measuring $8 \times 2\frac{3}{4} \times 2\frac{1}{2}$ inches.

But perhaps the best portable microscope yet designed to combine perfect efficiency with complete portability and moderate price is that of Swift and Son. It is beautifully finished in brass, and is suitable for travelling, for clinical and for field work, or for home use. It is furnished with both coarse and fine adjustments, the latter being markedly superior to those usually fitted to microscopes of this type. The optical tube slides in its fitting so as to allow very low-power objectives to be used, whilst the draw-tube permits of an extension to 7 inches. The stage is larger than usual, and contains a sub-stage ring fitted with Abbé condenser of full size and iris diaphragm. The back leg is divided so as to pass over the fine adjustment screw when folded, whilst the stage is hinged, and lies flat against the body of the microscope. The whole packs into a leather case $9 \times 3 \times 3$ inches, with space for two objectives, live-box, small bottle, and sundry minor apparatus, as shown in the illustration (Fig. 27), and costs, without objectives or other apparatus, £5.*

W. Watson and Sons make a portable microscope

* Since the above was written, Swift and Son have brought out a new folding microscope for clinical work, in which the tail-rod is made to serve as a front leg, and which fits into a pocket-case $6\frac{1}{4} \times 3\frac{1}{4} \times 1\frac{3}{16}$ inches.

similar to the 'Edinburgh B' stand, but with folding tripod legs and mirror stem, and taking universal-sized fittings throughout. Messrs. Watson also make this stand with any sized body, so as to take other eyepieces if requisite.

Bausch and Lomb make a travelling microscope which screws into the top of its own case, the lid of which can be adjusted to give the necessary inclination.

Leitz makes a large and small travelling microscope, both of the Continental type. In the larger stand the foot folds in a **V** shape, as in Messrs. Beck's stand, and the mirror and stage are removable. There is coarse adjustment by rack and pinion and fine adjustment by micrometer screw, and sub-stage ring for illuminator. The smaller stand screws into the bottom of its leather case so as to form a base. It is provided with sliding coarse adjustment, and the fine adjustment is a screw fitted into the lower end of the tube just above the objective. There is no sub-stage.

Reichert's portable microscope is very similar to Leitz's larger travelling microscope.

Petrological and Chemical Microscopes.—It is unnecessary for us to discuss microscopes designed for special work, such as the engineering microscopes made by nearly all the leading makers, though we may mention in passing a recent microscope designed by Professor Chamot, of Cornell University, for chemical work, and made by Messrs. Bausch and Lomb. It is really a petrological microscope without means of inclination, and the author had a very similar microscope constructed for him some time previously for the same purpose by Messrs. Watson and Sons, which was fully described in an article contributed to the *Illustrated Annual of Microscopy* for 1900 (Fig. 28). The

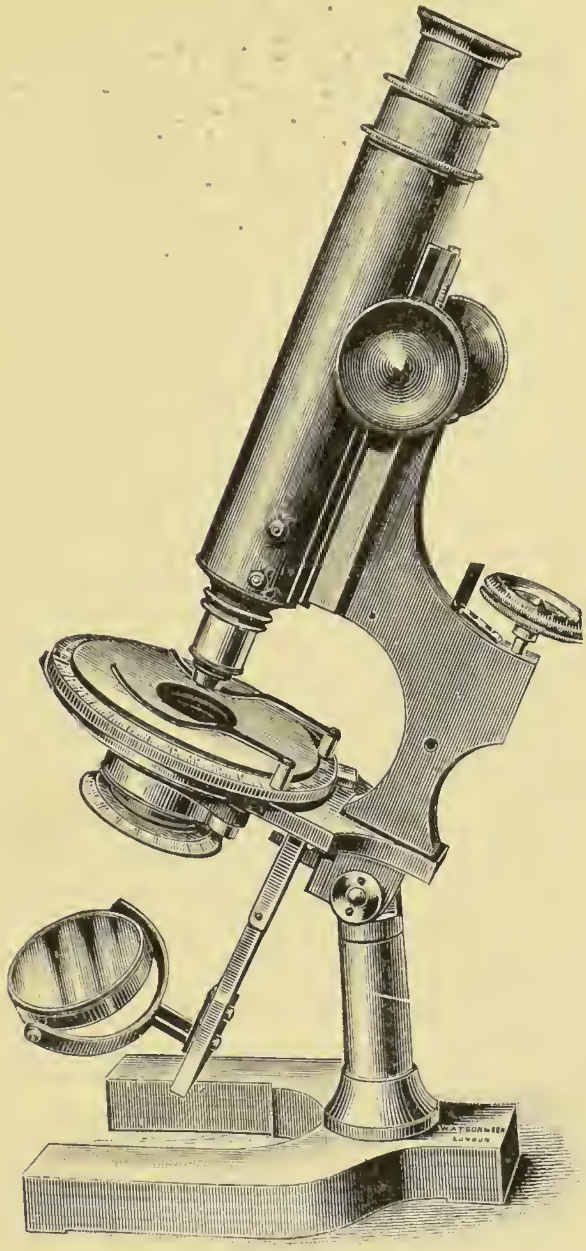

FIG. 28.—WATSON'S PETROLOGICAL AND CHEMICAL MICROSCOPE.

following description applies to most of the microscopes made for petrological purposes by nearly all the leading makers, though this microscope, being used mainly for micro-chemical analysis, was provided with a glass stage carefully extended to cover the graduations. The objectives used for such purpose are of the less expensive students' type, and when working with reagents likely to give off injurious gases the front lens can be protected by the simple device of attaching a small piece of thin cover-glass by glycerine or balsam. A means of exactly centring the stage with the optic axis of the microscope is provided, as the centres of various objectives always vary more or less, and this may be either by centring screws to the stage or by a centring nosepiece for the objectives. Beneath the stage is a fitting for condenser and polarizing apparatus, so arranged as readily to swing out. The polarizer is graduated on its circumference, and provided with stops at each 90 degrees of rotation, and the optical part of the condenser is so arranged as to fit above the polarizer when it is necessary to increase the light for high or medium powers. Above the polarizer can also be placed a removable high-angle condenser system for examination of crystals, etc., in convergent light. The analyser is placed above the eyepiece, both for convenience and to increase the light, and it also is accurately divided on its circumference. Both it and the polarizer are pinned so as to insure the uniformity of their positions. In ordinary microscopes the analyser is often fitted into a ring which screws above the objective. The eyepiece is provided with cross-wires, and the two Nicol prisms are accurately placed so that their principal sections coincide with these cross-wires. Between the eyepiece and the analyser can be further

placed a calc-spar plate for stauroscopic examinations. The draw-tube draws right out, and is provided with a Bertrand lens for use with the eyepiece, in order to magnify the interference figures shown by convergent

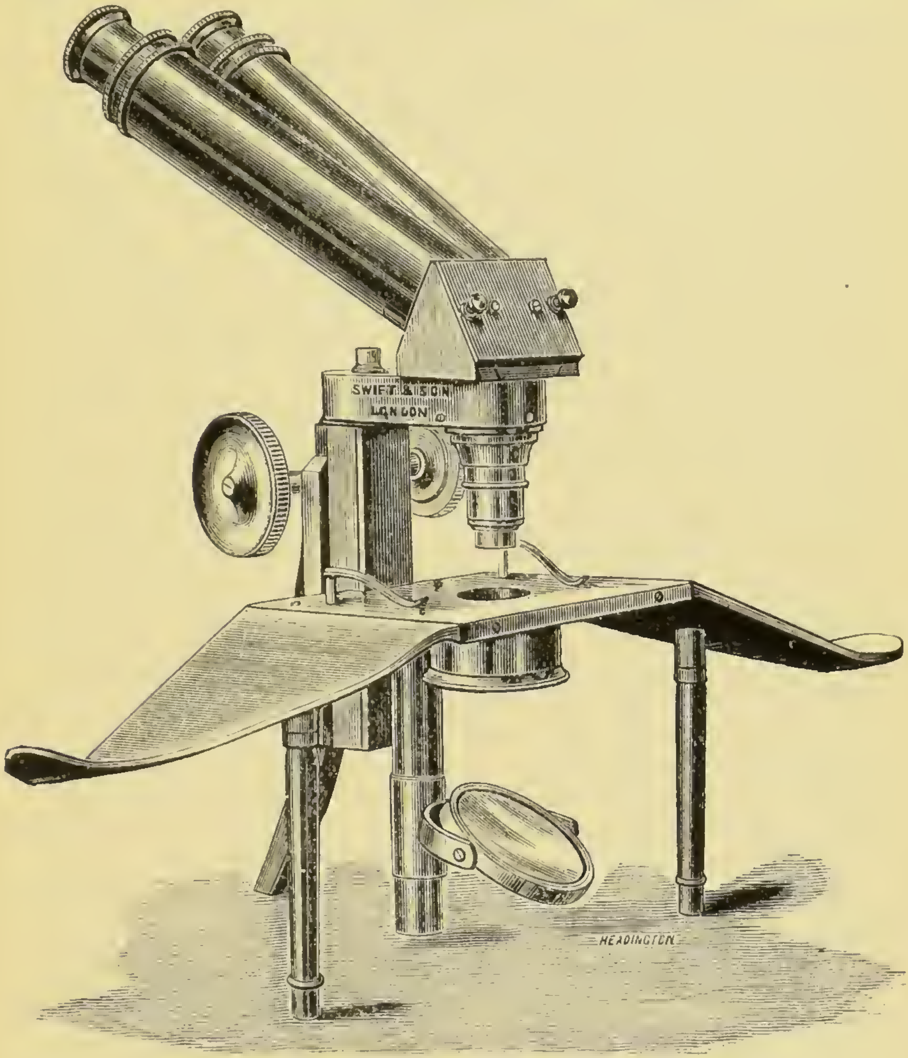

FIG. 29.—SWIFT'S 'STEPHENSON' BINOCULAR MICROSCOPE.

polarized light. In a slot in the body slides a Klein's quartz plate for distinguishing weakly refractive crystals, and a quartz wedge and quarter undulation

plate for determining the positive or negative character of crystals. A bi-quartz eyepiece is sometimes added. Finally, the pitch of the fine adjustment is definitely known and the milled head graduated, as by using a high power the refractive index of thick specimens may by this means be approximately determined. Accessories for taking micrometric measurements and a simple form of camera lucida are desirable additions. J. Swift and Son make a beautiful and elaborate form of petrological microscope, designed by Mr. Allan Dick, in which the stage itself is stationary, whilst the body tube and sub-stage rotate together.

Dissecting Microscopes.—Amongst microscopes designed for special purposes must be included dissecting microscopes, which range from a simple hand-lens, mounted on a stand, to elaborate compound instruments. Of these, the most noteworthy is the binocular microscope designed by Mr. Stephenson, and made by J. Swift and Son. The illustration (Fig. 29) will show this instrument better than a description. There are two prisms above the objective, so that the light is equally divided in each tube, whilst the image by means of a *mirror* is reflected into the tubes and so *erected*. The inclination of the tubes obviates the necessity for inclination of the body, and a fine adjustment is not necessary, as high powers are not used with a binocular. There is a sliding adjustment for width between the eyes, and a plain sub-stage ring for condenser, etc. Being specially designed as a dissecting microscope, it is furnished with leather-covered hand-rests. It forms the most convenient and efficient instrument of its class known to the author, and is unrivalled for delicate dissections. As a binocular microscope it seems to us to fulfil every requirement if provided with proper condenser. The price of the stand, with two eyepieces, is £9 10s.

Messrs. Swift make a similar but much more elaborate stand, with full mechanical accessories, at a higher price.

Greenough's binocular is a simple upright stand without sub-stage, and carrying a separate objective at the bottom of each tube. The tubes are set at an angle to each other so as to bring an independent image of the object into focus in each tube. It has rack and pinion focussing adjustment. The objectives are of about $\frac{1}{2}$-inch focus, and the instrument has the manifest drawback of being confined to this magnification, though a pair of high-power eyepieces can vary it from 25 to, say, 40 diameters. It is, however, a most efficient instrument, and gives true stereoscopic vision. As made by Leitz, the instrument has rack-work adjustment to the draw-tubes, and costs, with the necessary objectives, etc., £7 10s., or, with erecting prisms, £10. As made by Zeiss, a pair of Porro prisms, of similar design to those in use in the now familiar prismatic binocular field-glasses, are used to erect the image, and by their rotation afford a ready means of adjusting the inter-ocular distance. By using different pairs of objectives and eyepieces the magnifications vary from 8 to 72. The price of this stand, without objectives, etc., is £9 15s. Zeiss mounts a similar microscope upon an elaborate lengthening arm giving universal movements, and Leitz (Fig. 30) mounts a couple of Brücke lenses in a most convenient way upon a long arm and extending upright, adjustable by thumb-screws. A rack and pinion is provided for focussing, and there is a joint to adjust for inter-ocular distance. This is a most convenient stand, with a working distance of not less than 4 inches, but the magnification is only 4 diameters. The price is £3.

Most dissecting microscopes are, however, simple lenses of the aplanatic or less expensive type, mounted

either in a holder or on a stand. Wherever possible an aplanatic triplet, as described on p. 5, should be selected, its relatively large working distance and perfect corrections saving the eye much fatigue in prolonged work. The Continental makers show a decided superiority over our own makers in the stands to hold these lenses, both in design and in cheapness, combined with good work. Leitz makes a simple dissecting

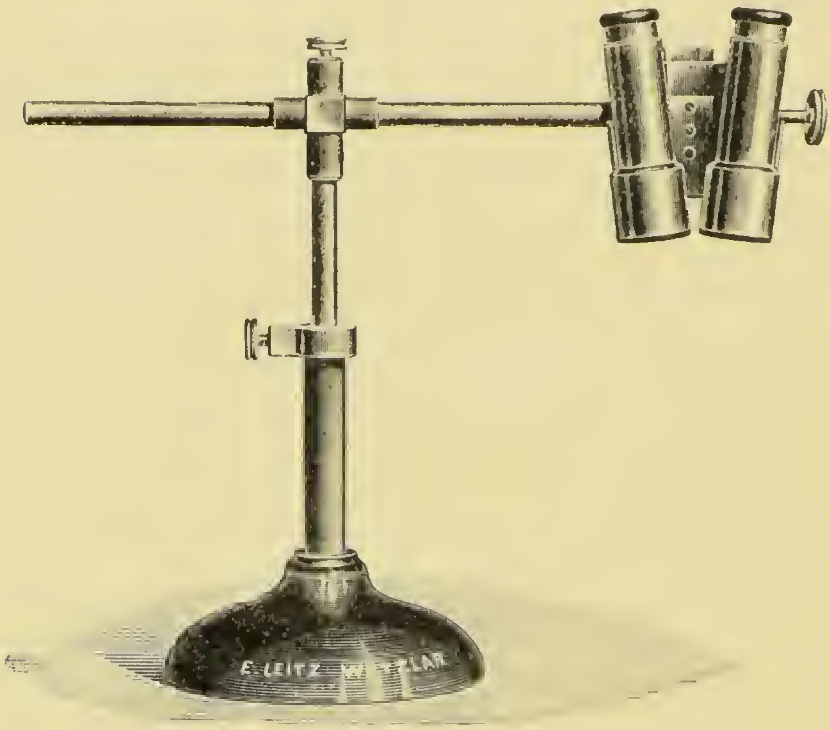

FIG. 30.—LEITZ'S DISSECTING MICROSCOPE.

stage with white glass plate and movable lens-holder for 5s., and various forms of movable arms giving universal movements at prices ranging from 8s. to 18s. His most noticeable dissecting microscope (Fig. 31) is an upright stand bearing a square glass stage, provided with springs, lens-holder adjustable by rack and pinion, movable plane mirror and white glass plate, movable hand-rests, complete in box, price £1, or with two

aplanatic lenses, magnifying 10 and 20 diameters respectively, £2. A larger stand of very similar design costs £2 without lenses. Reichert, Zeiss, and Bausch and Lomb make very similar dissecting stands, and for ordinary work this pattern cannot be surpassed. Another good form of inexpensive dissecting stand is made by Bausch and Lomb. It is cut out of a solid block of wood, shaped so as to form hand-rests. The glass stage is extra large, and is easily removed for cleaning. The mirror is rectangular, and is as large as the stage, being set at an angle beneath it. A plate, with a black and white side, is stowed beneath the

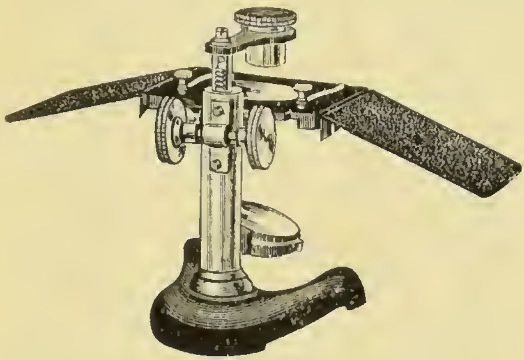

FIG. 31.—LEITZ'S DISSECTING STAND.

stand, and may be laid over the mirror to form a black or white background as desired. The lens-carrier slides in a metal sleeve, which is firmly fixed in the wooden base. The price of this stand, with one doublet lens magnifying ten times, is only 9s., or, with extra doublet lens magnifying five times, 12s.

Lens-Holders.—Most of our English makers have simple holders for lenses at varying prices, and two or three make larger dissecting stands of a rather primitive type, with fixed hand-rests, and costing generally from £2 2s. to £2 10s. Various types of demonstration microscopes for classes are also sold, varying from a

simple handle holding a microscopic slide, and an aplanatic lens above it, to a more elaborate tube carrying eyepiece and objective within the body, the slide being supported by springs on a plate at the end. Either of these can be readily handed round a class.

Tank Microscope.—Finally, we may mention the Tank microscope (Fig. 32), designed by Mr. C. F. Rousselet, for rapidly looking over pond-water, weeds, etc. It is made by C. Baker, and consists of a metal-bound tank

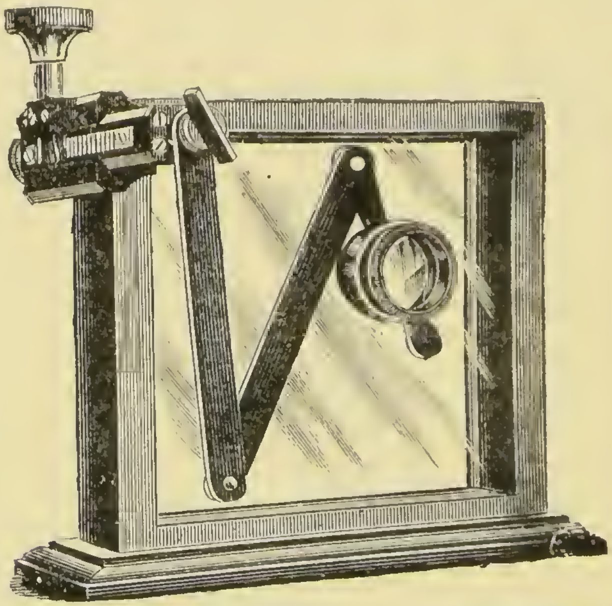

FIG. 32.—ROUSSELET'S TANK MICROSCOPE.

$7\frac{1}{2} \times 5\frac{1}{2} \times 1$ inches, standing on edge, on a broad base, to which is added an upright with a jointed arm carrying an aplanatic lens of long focus, say × 8 inches, which can be moved to any part of the tank, and is adjustable by rack and pinion. The cost of the tank alone is 10s. 6d., and of the base and arm 35s., or, with counterpoise, 40s. The latter can be detached and clamped to another base for use as a dissecting microscope.

CHAPTER IV

OBJECTIVES AND EYEPIECES

Achromatic Objectives.—It now becomes necessary to speak of the purely optical parts of the microscope, the most important of which is, of course, the objective. The improvement in objectives of late years has been enormous, and for a reasonable sum the microscopist can now get lenses with a definition that leaves but little to be desired. This is largely due to the use of the newer forms of glass, known generally as Jena glasses, but also to entirely new computations by means of which aberrations have been largely reduced. This is evident not only in the clearness and brightness of the image as well as in its definition, but also in the increased ability of the objective to bear high eyepiecing without an immediate loss of definition. It is a mistake, however, to suppose, as is so often stated, that *any* objective will bear very high eyepiecing without depreciation in the image, and this is most evident with the higher powers, but many of the later achromatics will now stand *moderate* eyepiecing nearly as well as the apochromatics. In fact, we have had in our hands quite recently achromatic objectives which, except that the chromatic corrections are necessarily less perfect, would compare favourably in definition, in brightness of image, and in power to bear high eyepiecing with

the apochromatics. This is the more important as the price of these latter lenses is almost prohibitive to workers of moderate means, a $\frac{1}{12}$-inch oil immersion by Zeiss costing £15 to £20, according to its aperture. The reader may rest assured, therefore, that good achromatics, by first-class makers, will show him *almost* all that the microscope is capable of revealing.

Rating of Objectives.—In Chapter VI. it will be explained (see p. 114) that the terms 1 inch, $\frac{1}{4}$ inch, etc., as applied to objectives, do not represent the distance between the under side of the front lens and the object, but represent the approximate initial magnifying powers without eyepiece at a distance of 10 inches from the back lens. Owing to the difficulty of making objectives of high aperture and proportionately low magnifying power, objectives will often be found to be of higher magnification than they should be. An inch will be nearer $\frac{3}{4}$ inch, $\frac{1}{2}$ inch nearer $\frac{1}{3}$ inch, and so on. The *testing of objectives* requires much practice and education of the eye.

Choice of Objectives.—With regard to the choice of individual objectives by different makers, we strongly recommend the beginner to get his objectives only from the very foremost makers. Their selection is a most important matter, and it is here that the advice of a really competent friend becomes valuable. When all is said and done, the objective is, after all, the most important part of the microscope. Microscopes are often quoted with a 1-inch and a $\frac{1}{4}$-inch or $\frac{1}{6}$-inch objectives. It generally pays, therefore, to purchase the objectives, where possible, or at any rate some of them, from the maker of the microscope, as several makers charge a little less in such cases than if the items are bought separately. In fact, certain makers do not sell their stands alone.

Apochromatic Objectives.—The apochromatics are high in price, but there is no doubt of their superiority to other objectives, and those who propose to do critical and original research work will purchase them accordingly. Messrs. Zeiss, owing to the prestige gained by Professor Abbe's investigations, and to the fact that they first put these lenses upon the market, make more apochromatic lenses than all other makers combined, and are in consequence able to turn them out with exceptional uniformity. Whether their high price is justified is another matter. As dry lenses they make 1-inch and $\frac{2}{3}$-inch of N.A. 0·3 at £6 and £4 respectively; a $\frac{1}{2}$-inch and $\frac{1}{3}$-inch of N.A. 0·65 at £7 and £5 respectively; and a $\frac{1}{4}$-inch, $\frac{1}{6}$-inch, and $\frac{1}{8}$-inch of N.A. 0·95 at £9, £7, and £8 respectively. They make also a water-immersion $\frac{1}{10}$-inch of 1·25 N.A. at £12 10s., and oil-immersions $\frac{1}{8}$-inch and $\frac{1}{12}$-inch of N.A. 1·3 at £15 each, and a $\frac{1}{8}$-inch and $\frac{1}{12}$-inch of N.A. 1·4 at £20 each. All these are made either for the short or long tube as required, with the exception of the 1-inch, the $\frac{1}{2}$-inch, and the $\frac{1}{4}$-inch, which are made for the long tube only. It will be noticed that the N.A. of these lenses is exceptionally high, the $\frac{1}{4}$-inch in particular being a most difficult lens to construct. The $\frac{1}{2}$-inch of 0·65 N.A. is considered the finest dry lens on the market, and the $\frac{1}{8}$-inch oil-immersion of 1·4 N.A. is considered equally the finest immersion lens. A complete battery for an advanced worker with a deep enough pocket might be taken as including the 1-inch, the $\frac{1}{2}$-inch, the $\frac{1}{6}$-inch, the $\frac{1}{8}$-inch of the higher aperture, and the $\frac{1}{12}$-inch of the lower aperture, all corrected for the 10-inch tube. The $\frac{1}{6}$-inch might be recommended in preference to the $\frac{1}{4}$-inch as being more generally useful, and as being more uniform in quality. The lower aperture of 1·3 N.A. is recommended for the

$\frac{1}{12}$-inch in preference to that of 1·4 N.A., not so much because it is less in price, but because, as the makers state, the resolving and defining power of the latter is only 8 per cent., and the brightness of its image only 14 per cent., more than those of the lower apertured lens of the same power, whilst the more than hemispherical form of the front lens makes it difficult to mount, and as a result it is easily damaged or displaced. The shorter working distance, 0·2 millimetre as against 0·25 millimetre, constitutes another drawback to its use, unless the maximum of resolution is imperatively required. Messrs. Zeiss actually make (to order only) a $\frac{1}{10}$-inch mono-bromide of naphthalin immersion lens with the extraordinary N.A. of 1·6 (equivalent to the refractive index of this medium), which has been used by Dr. Henri Van Heurck, of Antwerp, for his exquisite photographs of diatom structure; but it necessitates the use of special cover-glasses and mounting medium of the same high refractive index, and a medium has not yet been found which could be used for objects other than diatoms without destroying either their structure or colour, or damaging the front lens of the objective. This drawback militates against the wider use of the objective, whilst the price is not less than £40.

Powell and Lealand lost no time in manufacturing apochromatic objectives according to the new formulæ, and their lenses are stated by competent observers to be not inferior to those of Zeiss, though possibly a shade less uniform, the apertures and prices being about the same. The writer has not himself much knowledge of these lenses, however, except of a $\frac{1}{12}$-inch oil-immersion of N.A. 1·4 sold at the exceptionally low price of £10, but which does not equal Zeiss's $\frac{1}{12}$-inch of the same aperture,

or Powell and Lealand's own similar lens at a considerably higher price.

We believe the only other makers of apochromatics in this country are J. Swift and Son, who make a $\frac{1}{8}$-inch oil-immersion of 1·3 N.A. at £8 8s., and a $\frac{1}{12}$-inch oil-immersion of 1·4 N.A. at £10 10s.

On the Continent apochromatics are made by most of the leading opticians, such as Leitz, Reichert, Seibert, and Nachet, and in America by Bausch and Lomb, mostly at rather lower prices, but of these lenses also the writer has had no experience.

Semi-apochromatic Objectives.—The most notable advance in recent years is, however, the improvement in achromatics, due largely to the use of the new Jena glasses, and to this we have previously alluded. Such objectives are often spoken of as semi-apochromatics, or by trade designations, and though one may object on principle to the multiplication of descriptive names, the more recent lenses almost deserve some such title to distinguish them from the earlier achromatics, for they run even the apochromatics very close. We have no intention of favouring any one maker more than another, but in the interests of those for whom this book is written, we think we are justified in calling particular attention to the new series of achromatic objectives recently introduced by W. Watson and Sons. These lenses are known by the trade name of 'Holoscopic.' They are constructed from computations of Mr. A. E. Conrady, and in addition to the new glasses, by the use of a triple combination back lens, succeed in correcting spherical aberration in what may be truly described as a very remarkable manner. They have the same corrections as the apochromatic lenses, and require, therefore, compensating eyepieces (see p. 76) for their proper per-

formance, whilst several of them equal the apochromatics in their N.A. We have carefully tested several of these lenses, and except, as may be expected, for a certain slight amount of outstanding colour on critical tests, they are almost indistinguishable from the best of the apochromatics, and bear high eyepiecing almost equally well. The most notable lens of the series is a $\frac{1}{2}$-inch of N.A. 0·65, sold at £3 10s., thus having the high optical index of 31·5; whilst following closely upon this is a 1-inch of N.A. 0·3 at £2 5s., and a $\frac{1}{4}$-inch of N.A. 0·94 at £4. All these, except the $\frac{1}{2}$-inch, are corrected for the short or long tube-length as required. In the same series are other objectives of smaller apertures and proportionately lower prices, and Messrs. Watson and Sons have also made $\frac{1}{8}$- and $\frac{1}{12}$-inch oil-immersions of the same character.

Achromatic Objectives.—In ordinary achromatic objectives, of what is generally known as the students' series, there is a wide choice, but it is worth noticing that each maker has one or more objectives that are specially good. Taking some of the leading English makers alphabetically, we may call attention to a fine $\frac{1}{12}$-inch oil-immersion of 1·3 N.A. sold by Chas. Baker at £5 as being, perhaps, the best lens of this maker. R. and J. Beck make two excellent $\frac{1}{4}$-inches of 0·68 N.A. at 21s. and £2 respectively, the latter being provided with a correction collar. We consider these two lenses about the best of their power on the market, it being a curious circumstance that the average maker does not show to advantage in his $\frac{1}{4}$-inch objectives, and that for one good $\frac{1}{4}$-inch there are half a dozen good $\frac{1}{6}$-inches. Amongst oil-immersions by these makers we may mention an excellent $\frac{1}{10}$-inch of 1 N.A. at £3, a $\frac{1}{12}$-inch of the same aperture at £4, and two $\frac{1}{12}$-inches of 1·25 N.A. and 1·4 N.A. at £5 and £8 respectively. The moderate aperture

of the first two of these immersion lenses is no drawback for the purposes for which most students require them. Messrs. Beck have also recently issued two $\frac{1}{14}$-inch immersions of 1·0 N.A. and 1·25 N.A., sold at £4 and £5 respectively, of which we can speak highly. Messrs. Ross send out an excellent $\frac{2}{3}$-inch of N.A. 0·26 at 25s., and an even better $\frac{1}{6}$-inch of N.A. 0·65 at £2, with their 'Standard' microscopes, as already described. Both of these are arranged so as to work in approximately the same focal plane when rotated on a nosepiece, by which re-focussing is reduced to a minimum. A $\frac{1}{8}$-inch and a $\frac{1}{12}$-inch oil-immersion, both of 1·2 N.A., at £5 each, are also fine lenses. J. Swift and Son have always held a foremost position as makers of objectives, and we may call attention to the excellent quality of the lenses supplied with their 'Histological and Physiological' microscope. These include a $\frac{1}{2}$-inch of N.A. 0·35, priced at 30s., and a $\frac{1}{6}$-inch of N.A. 0·83 at £2, which are both flat in the field and of excellent definition. J. Swift and Son's two best lenses are, in our judgment, a $\frac{1}{2}$-inch of N.A. 0·5, sold at £2, which is a really beautiful lens, bearing high eyepiecing exceptionally well, and a new $\frac{1}{12}$-inch oil immersion of 1·3 N.A., in which, we are given to understand, no less than seven different kinds of optical glass have been used. This lens gives a beautifully white and colourless field, and its definition is exceptionally brilliant. W. Watson and Sons' 'Holoscopic' lenses have been already alluded to, but in their ordinary series we must make mention of an excellent 2-inch of N.A. 0·15 at 22s., a $\frac{1}{6}$-inch of N.A. 0·87 at 30s., and a $\frac{1}{8}$-inch of 0·88 at £2. In oil-immersions a new $\frac{1}{12}$-inch of N.A. 1·10 has an unusually flat field and excellent definition, whilst their $\frac{1}{12}$-inch N.A. 1·25 at £5 is a lens well known for its special merit.

Continental Objectives.—The leading Continental makers have always held a high position for the excellence of their objectives, and as we have frankly criticised their microscopes, we are glad to be able to speak more than favourably of their objectives. Zeiss's achromatic series are well known, but are somewhat high in price as compared with other makers. Like all Continental makers, they still adhere to the confusing and obsolete custom of distinguishing these objectives by letters or numbers. Perhaps the best of the series, as well as the best known, are a 1-inch of N.A. 0·17 at 27s., and a $\frac{1}{6}$-inch of N.A. 0·65 at £2. Ernst Leitz, of Wetzlar, makes a brilliant series of lenses, of wonderful uniformity, amongst which we may select for special mention a $\frac{3}{4}$-inch of N.A. 0·28 at the low price of 15s.; a $\frac{1}{4}$-inch of N.A. 0·77 at 25s.; a $\frac{1}{6}$-inch of N.A. 0·82 at 30s., which is a well-known and beautiful lens; a fine $\frac{1}{8}$-inch of N.A. 0·85 at the same price; an oil-immersion $\frac{1}{10}$-inch of 1·3, sold at the exceedingly low price of £3 15s.; and a $\frac{1}{12}$-inch immersion of the same aperture at £5, both of which are lenses of exceptionally brilliant performance. C. Reichert, of Vienna, makes lenses not inferior to the foregoing, amongst which may be mentioned a semi-apochromatic $\frac{1}{5}$-inch of N.A. 0·5 at 32s.; a $\frac{1}{6}$-inch of N.A. 0·85 at 30s., which is one of the best $\frac{1}{6}$-inches known: and amongst oil-immersions a $\frac{1}{7}$-inch of N.A. 1·3 at £8, which in some respects stands almost alone; an excellent $\frac{1}{12}$-inch of N.A. 1·3 at £8; and a but little inferior lens of the same power, but of N.A. 1·25, at £5. Messrs. Seibert, of Wetzlar, also make fine objectives; and quite recently objectives by a comparatively new maker—Mr. Otto Himmler, of Berlin—have been submitted to us, which showed once more how near the best and newest achromatic lenses come to the more costly

apochromatics. These particular lenses were $\frac{1}{8}$-inch and $\frac{1}{12}$-inch oil-immersions, with N.A. 1·3. Both were excellent, but the $\frac{1}{8}$-inch was one of the finest achromatics we have seen, possessing brilliant definition. The price of the $\frac{1}{12}$-inch was £4 10s., and of the $\frac{1}{8}$-inch only £3 5s. In the United States the Bausch and Lomb Optical Co. must not be omitted. We have tested the lenses generally sent out with their stands—notably a $\frac{2}{3}$-inch of N.A. 0·24 at 16s., and a $\frac{1}{6}$-inch of N.A. 0·85 at 30s.—and found them particularly free from colour and of excellent definition, whilst a $\frac{1}{12}$-inch oil-immersion of N.A. 1·32 at £5 3s. proved equally fine. The Spencer Optical Co.'s lenses have not come under our notice.

We think no apology is needed for the mentioning of so many objectives by different makers, and for adding the prices. We wish, as far as possible, to help the beginner to make a satisfactory choice; and though the objectives mentioned are, of course, merely selections, they have been selected from personal experience, and the opinions expressed are in many cases endorsed by the experience of others. The best all-round objective for the beginner is the 1-inch, after that the $\frac{1}{4}$-inch or $\frac{1}{6}$-inch—the former preferably for botanical work, and the latter for human histology. As the worker becomes further advanced, he will wish to add others. The 2-inch is a most useful lens, as it takes in a large field; the $\frac{1}{2}$-inch comes in between the 1-inch and the $\frac{1}{4}$-inch, and a $\frac{1}{8}$-inch (dry) is useful in certain circumstances. Any higher power than this should be an immersion lens, preferably oil immersion. But the beginner is not advised to get really high powers until he actually requires them. He will soon realize that mere magnification is by no means the main object in microscopical

work, and that the real worker invariably uses the lowest power he can.

Oculars.—The necessary **eyepieces** must now be dealt with, and on this matter fewer words will be necessary than have been advisable with regard to objectives. The eyepiece most frequently met with is the '**Huyghenian**,' or '**negative**' **eyepiece** (Fig. 33), which is composed of two plano-convex lenses with a diaphragm in the principal focus of the eye-lens, the principle being explained on page 114. The diaphragm cuts off the

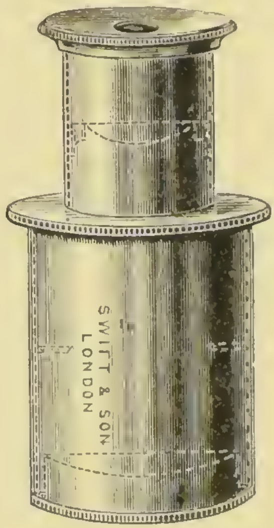

FIG. 33.—HUYGHENIAN OCULAR.

marginal rays, which suffer most from spherical aberration, and the fixed lens in this type of eyepiece assists in correcting the aberrations of the objective, and so tends to flatten the field.

The **Kellner Eyepiece** (Fig. 34) is variously stated as both a positive and a negative eyepiece, the fact being that the field-lens is *in* the focus of the eye-lens. This field-lens is biconvex, whilst the eye-lens is an achromatic doublet meniscus. The field is only bounded by

the diameter of the tube, and is therefore proportionately large—in fact, in a microscope with a large tube and correspondingly large eyepiece it may take in a field larger than is advisable, in consideration of the increasing

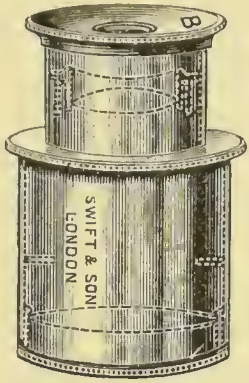

FIG. 34.—KELLNER OCULAR.

marginal aberrations of the objective. Their definition is not quite so good as that of the negative eyepieces, and they show dust on the field-lens readily, but for

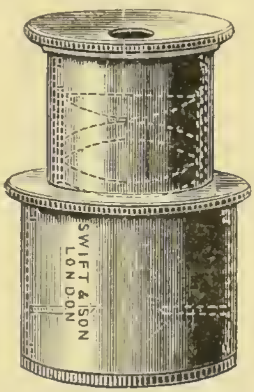

FIG. 35.—RAMSDEN OCULAR.

low-power work their large field makes them often useful.

The **Ramsden Eyepiece** (Fig. 35) is really a positive eyepiece, which means that its focus is slightly outside

the field-lens, and it can therefore be used as a magnifying-glass. It consists of two plano-convex lenses, with their plane sides outwards. They were formerly used as micrometer eyepieces, the micrometer divisions being readily magnified by this means, but the micrometer is now generally placed in the position of the diaphragm in a Huyghenian eyepiece.

Compensating Oculars.—The **Compensating Eye-pieces** of Zeiss and other makers are specially constructed for use with apochromatic objectives, in which, as hereafter explained (p. 106), certain outstanding corrections are deliberately left to be rectified by the eyepiece. The apochromatic objectives being left under-corrected, the compensating eyepieces are made correspondingly *over*-corrected. Strictly speaking, it was only the high-power apochromatic objectives that required to be left under-corrected in this way; but, to permit of the use of these eyepieces throughout, the same under-correction is put into the low-power apochromatic objectives also. These eyepieces are made with initial magnifications stated as 2, 4, 6, 8, 12, 18, and 27, the first three being Huyghenian eyepieces with achromatic eye-lenses; but the higher powers are positive, containing an achromatic double convex triplet with a single plano-convex lens above it. The field is limited to 6 inches, for the reasons mentioned when dealing with Kellner eyepieces. The compensating eyepieces all work in the same focal plane, and the necessary re-focussing after a change of eyepiece is thus reduced to a minimum, whilst the corrections of the objective are not disturbed. The initial magnifications of the eyepieces are marked upon them, and they are true to their designations so far as those made for the English size and length of tube are concerned, but there the consistency ends. As a matter of fact, the same

eyepieces are made of a smaller diameter for the Continental length of tube, with which, of course, they work equally well so far as regards tube-length, but they are then marked with a lower number calculated from the combined magnification, which has diminished, owing to the objective no longer forming its image at 10 inches but at 6, as if *they*, and not the objective, were responsible for the decreased total magnification. It has led to much confusion and misunderstanding. Most Continental opticians, however, and unfortunately not a few English opticians also, persist in giving in

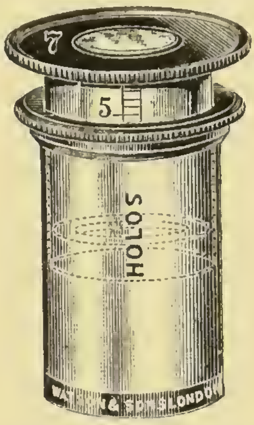

FIG. 36.—WATSON'S 'UNIVERSAL' OCULAR.

their catalogues tables of combined magnification in which the objectives corrected for the short tube-length are treated as if they gave the full 10-inch magnification, and the powers of the eyepieces are correspondingly understated. Why cannot the initial magnification of the ocular be treated as an independent and unvarying quantity, and the magnification of an objective be admitted to depend upon the distance at which it is designed to form its image? Before leaving the compensating eyepieces, we may mention that, owing to the fact that ordinary high-power achromatic objectives

have errors leading to under-correction, the compensating eyepieces distinctly improve the performance of such objectives.

Universal Oculars.—W. Watson and Sons and J. Swift and Son have recently introduced adjustable negative eyepieces in which the eye-lens is mounted in a short draw-tube within the tube carrying the field-lens, this tube being capable of an adjustment of about 10 millimetres (Fig. 36). The side of the draw-tube is graduated accordingly. When the inner tube is pushed home the eyepiece magnifies all colours equally, and is suitable for use with low-power achromatic objectives (which are generally over-corrected), but when the inner tube is drawn out the eyepiece magnifies red more than blue, and becomes a compensating eyepiece for use with all apochromatic and with high-power achromatic objectives, as above stated.

Eyepieces are made either in the students' form, as in Fig. 36, or with caps upon them, as in Fig. 33. The capped eyepieces are used mainly for the larger English stands. The students' type of eyepiece costs from 5s. to 7s. 6d., whilst the capped eyepieces will cost about twice as much. Watson's adjustable eyepieces cost 17s. 6d. each for the students' form, and 22s. 6d. for the capped form. Zeiss's Compensating eyepieces cost from 20s. to 35s. each.

Choice of Oculars.—The magnifications of eyepieces range from 4 to 15, or even higher. In choosing them, it should be borne in mind that an initial magnification of 5 or 6 is about the lowest that can be satisfactorily used on the short tube-length, for which nearly all the achromatic lenses mentioned in this chapter are corrected, and that, on the other hand, few achromatic objectives, even of low powers, will satisfactorily bear really high

eyepiecing. We are quite aware that all makers sell eyepieces of much higher powers, as mentioned above, but very few of the ordinary achromatic objectives will satisfactorily and *critically* bear eyepiecing above ten times with a 10-inch tube-length. It is only the apochromatics that will bear very high eyepiecing, and even in their case the loss of light and depreciation of the image is noticeable. But until the apochromatics were invented the only way to get high magnification was to use high-power objectives, such as $\frac{1}{25}$- and $\frac{1}{50}$-inch,

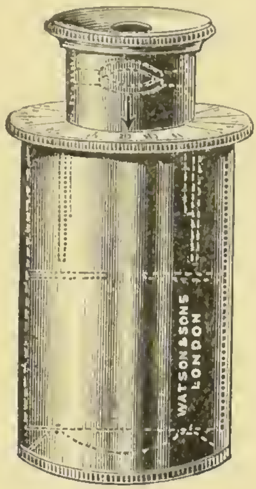

FIG. 37.—PROJECTION OCULAR.

which we so seldom hear of nowadays. If the microscope is provided with two eyepieces, therefore, we would suggest that the 6 and 10 should be chosen. They should all work in the same focal plane, should fit easily in the draw-tube, in order to obviate any risk of forcing the objective down on the cover-glass, and should be marked with their actual magnifications, instead of arbitrary figures or letters.

Projection Ocular.—There are certain eyepieces that are used for special purposes. Amongst these is the

Projection Eyepiece (Fig. 37), used with the photo-micrographic camera, and for other projection purposes. It possesses a collective field-lens and an achromatic biconvex triplet eye-lens. This eyepiece should be free from secondary chromatic aberrations, and the visual and actinic foci should coincide. A limiting diaphragm is placed between the lenses, which must be focussed upon the screen used. These eyepieces are over-corrected, like the compensating eyepieces, and are intended to be used with apochromatic or high-power achromatic objectives. They give beautiful definition for projection purposes, and are necessary for the highest class of photo-micrography, though the compensating oculars, and with low powers even the ordinary negative eyepiece, give good results. The projection oculars are made in powers of 3 and 6, and can be used either for the 10-inch or the 6-inch tube. In the latter case they are mis-described as magnifying 2 and 4 times respectively.

Micrometer Eyepiece.—The **Micrometer Eyepiece**, as well as spectroscopic and polarizing eyepieces, will be dealt with under accessories. The **Binocular Eyepiece** is, we believe, only made by Zeiss, and for the short tube. It requires some practice.

A list of the standard eyepiece sizes has been given on p. 26, and in the Appendix, and no microscope should be purchased which does not conform to one of these.

CHAPTER V

ACCESSORIES

Sub-stage Condenser.—The **Sub-stage Condenser** is now admitted to be an essential portion of the equipment of the modern microscope. This valuable adjunct has, indeed, been long recognised by English microscopists and opticians to be indispensable, but it has only comparatively recently received due appreciation on the Continent. The majority of microscopical objects are examined by transmitted light, and the condenser serves to focus the light upon the object. As the qualities of modern objectives have advanced, so the condenser has been improved to keep pace with them, until now it is an optical masterpiece, second only in its corrections to the objective; and upon the perfection of these corrections much of the performance of a high-class objective on critical work depends.

Types of Condenser.—The present-day condenser is practically of two types—one *chromatic*, known as the 'Abbe illuminator,' and one *achromatic*. The former is the most popular, the cheapest, and the most frequently fitted to students' microscopes both in this country and abroad, but the superiority of the latter is daily bringing it more into prominence.

Abbe Illuminator.—The **Abbe Illuminator** is of two types (Figs. 38 and 39), a double combination with an aperture of 1·2 N.A., and a triple form of 1·4 N.A. Of course, when the whole of this aperture is required the condenser must be in immersion contact with the

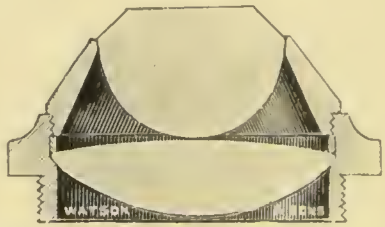

FIG. 38.—ABBE ILLUMINATOR (N.A. 1·2).

under side of the object slide. Both are simple, cheap, and easy to work, and are accordingly largely used by students; but in both the chromatic and spherical aberrations are very great, and they are therefore not satisfactory when used for critical work. The value

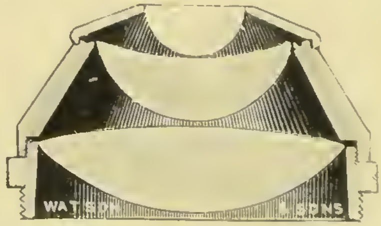

FIG. 39.—ABBE ILLUMINATOR (N.A. 1·4).

of a condenser depends upon the **aplanatic cone** (see p. 125) which it is capable of transmitting, and this, in the two condensers under discussion, is only about 0·5 N.A. At the same time, as we have just said, the beginner will find it a very useful form of condenser for general and

not too critical work. We prefer the 1·2 N.A. type, and it is also the cheaper of the two.

Achromatic Condensers.—The **Achromatic Condenser** of 1·0 N.A., made by most English and one or two Continental opticians, is much superior to the Abbe illuminator, not only because it is achromatic, but because it transmits an aplanatic cone approximating to its N.A., though this last is nominally less than in the chromatic forms. Its advantages are more especially noticeable in photo-micrography. Until recently it was somewhat heavy and cumbrous in shape, so that in many microscopes it had a tendency to foul the sliding-bar or mechanical adjustments of the stage. The later con-

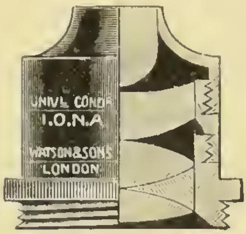

FIG. 40.—WATSON'S 'UNIVERSAL' CONDENSER.

densers of Baker, Beck, Swift, and Watson are compact in size and excellent in every way. As a type of these may be mentioned the last maker's 'Universal Condenser' (Fig. 40), which has a power of $\frac{1}{10}$ inch with N.A. 1·0, but is capable of transmitting an aplanatic cone exceeding 0·95. This is a useful condenser for moderate and high powers, and can be used with lower powers by removing the top lens, when the power becomes $1\frac{1}{3}$ inches; but the N.A. drops proportionately to 0·4 N.A., and a certain amount of chromatic over-correction becomes noticeable. The same makers have recently brought out a special condenser for use with low powers. It

has a clear aperture of $1\frac{1}{4}$ inches, and a focus of 2 inches, and it fits into the usual size of sub-stage.

Finally may be mentioned the oil-immersion condensers made by all the firms mentioned above, which enable the extreme resolving and defining powers of

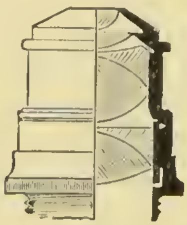

FIG. 41.—BECK'S IMMERSION CONDENSER.

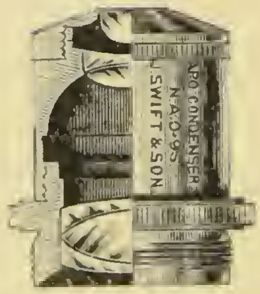

FIG. 42.—SWIFT'S APOCHROMATIC CONDENSER.

immersion objectives to be realized. Of these Beck's immersion condenser may be taken as an example (Fig. 41), having a N.A. of 1·4, and an aplanatic cone of 1·35.

Apochromatic Condensers.—Powell and Lealand and

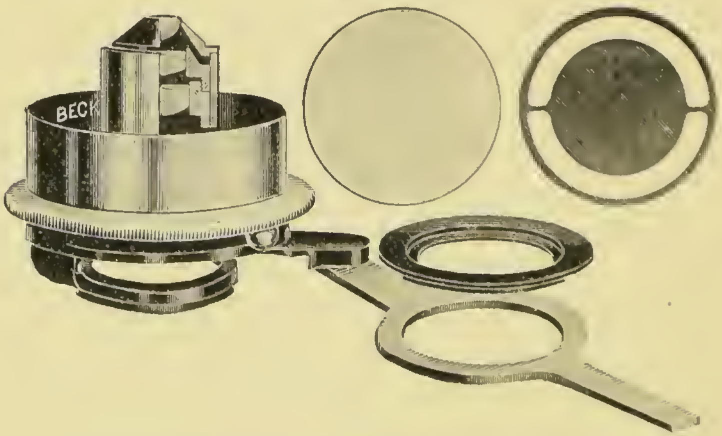

FIG. 43.—CONDENSER MOUNT AND FITTINGS.

Swift and Son (Fig. 42) also make apochromatic condensers, whose performances leave nothing to be desired even for the most critical work.

It may be added that the top lens of all condensers is generally removable, so as to give a larger illuminated field when a low-power objective is being used. The mount (Fig. 43) of the condenser is either carried by the focussing and centring stage mentioned when we dealt with stands, or it slides in a short tube-ring affixed to the under side of the stage. Of course, the former is much preferable, not only in the facilities it gives for focussing, but also for centring, though at least one maker provides a centring but non-focussing sub-stage ring, which can also be readily swung aside when not wanted. Beneath the condenser is fitted an iris diaphragm, or a ring to hold movable diaphragms, and there is generally also an additional turn-out ring into which stops can be placed to give oblique illumination (necessary at times for certain diatoms and similar work), or to give dark ground illumination by means of a central black spot, varying in size with the objective used. This gives most beautiful effects, but is not often used for critical work. The spot-lens proper and the paraboloid are not now much used.

Diaphragms.—An **Iris Diaphragm** is greatly superior in convenience at least to any form of **diaphragm plate,** whether it be a revolving plate or a series of stops. Under any circumstances the proper place for the diaphragm is beneath the condenser. Certain Continental stands provide two diaphragms, one beneath the condenser and attached to it, and one above for use when the condenser is removed. These microscopes also contain an ingenious refinement, already alluded to, by means of which the diaphragm can be racked backwards and forwards in a plane at right angles to the optic axis. In diatom work this is probably of service, and also for lens-testing, but for all general

purposes it seems to us to be as unnecessary as it is cumbrous and costly. It is certainly not rigid, and as the Continental sub-stage is generally guiltless of centring screws, it appears to be misplaced ingenuity to provide an elaborate means of *decentring* the diaphragm, which is seldom needed, without making any provision for the optical *centring* that is so essential in critical work.

Polarizing Apparatus.—**Polarizing Apparatus** is necessary for certain classes of work, mainly petrological and crystallographic, and gives beautiful effects on certain other objects, such as starch, textile fibres, hairs, horn, odontophores, etc. The **polarizer** (Fig. 44) fits into the sub-stage tube, where it is capable of rotation, and

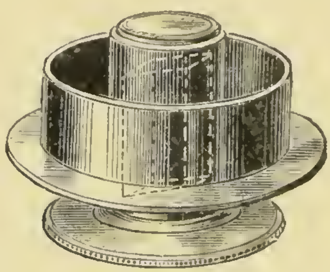

FIG. 44.—POLARIZER.

is generally graduated at intervals of 90 degrees or subdivisions of 10 degrees. The **analyser** (Fig. 45) either screws above the objective or is placed above the eyepiece. The latter place is preferable, as giving a brighter though smaller field. It is also graduated, and is capable of rotation. In use the two Nicol prisms are adjusted so that their planes of polarization cross each other, in which case the ray of plane-polarized light emerging from the first prism, or polarizer, is completely extinguished by the second, or analyser, and complete darkness results. Any doubly refracting substance now placed upon the microscope stage alters the refraction,

and by its 'interference' causes colour, or, at least, more or less marked variations of light and shade.

Selenites.—When the latter shades are very faint, due either to weak refraction or to extreme thinness in the object, it is advantageous to obtain a stronger contrast by using in addition a thin section of some more strongly refracting substance, such as **selenite** or **mica.** The selenites sometimes fit in caps over the polarizer, sometimes are mounted in separate rings, and sometimes are placed on the stage itself. The rotation of one of

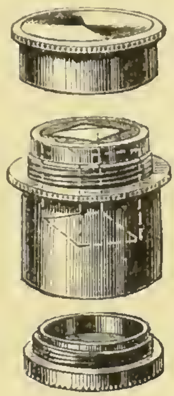

FIG. 45.— ANALYSER.

the Nicol prisms or of the selenite gives most beautiful effects.

It is, unfortunately, beyond the province of this book to go more deeply into the subject of polarization and its application by means of the microscope, and for this reason we must omit such accessories of the petrological microscope as the **quartz-wedge,** the **quarter undulation plate,** etc., and the **bi-quartz eyepiece**, nor must we deal with the means of showing rings and brushes in crystals by **convergent light.** It will, however, be found advantageous to have the polarizer so arranged that the optical part of whatever condenser is used fits also

above the polarizer, and comes into focus with objects on the stage. The author has found this of great service in militating against the serious loss of light due to the use of polarized light, especially with high-powered objectives and in photography.

Bull's-eye Condenser.—The **Bull's-eye Condenser** (Fig. 46) on the usual stand is a common adjunct of microscopes, but an unsatisfactory one. As ordinarily made, it is nearly hemispherical, and its chromatic and spherical aberrations are most marked. It can be used with transmitted light to strengthen the illumination from a lamp, or for opaque objects requiring illumination on the stage (reflected light), where either artificial light or daylight is the source of illumination.

Side Silver Reflector.—For objects to be used by reflected light the **Side Silver Reflector** (Fig. 47) is most convenient and effective. The Lieberkühn is now little met with for reasons explained on p. 134.

If the tail-rod carrying the concave mirror will allow of the latter being adjusted above the stage—a little detail far too often omitted by makers—excellent illumination can be got by this means, as previously stated.

Vertical Illuminator.—For illuminating opaque objects with high-power lenses, such as a $\frac{1}{12}$-inch immersion, a **vertical illuminator** (Fig. 48) is necessary. This illuminator is screwed into the nosepiece of the microscope above the objective. The lamp is adjusted so as to throw a strong beam of light through the aperture at the side, and within is a prism or a cover-glass set at an angle of 45 degrees, which reflects the light down through the objective on to the object, thus illuminating it. This piece of apparatus requires some care in adjusting, and can only be used for objects that are

either uncovered or in actual contact with the cover-glass.

Light Modifiers.—There are various means of modifying

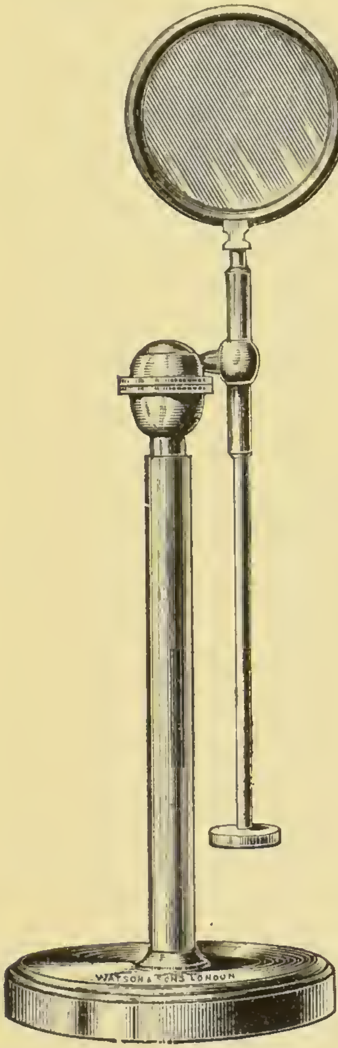

FIG. 46.—BULL'S-EYE CONDENSER.

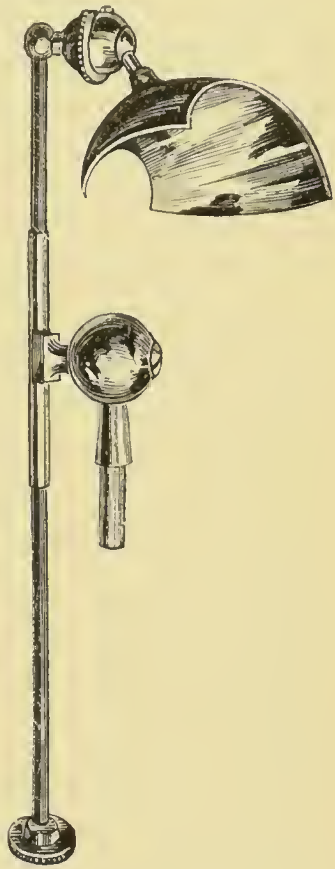

FIG. 47.—SIDE SILVER REFLECTOR.

the illumination, of which the simplest is by means of a blue glass chimney to the lamp, or, better, by using discs of blue or yellow glass to drop into the ring beneath

the condenser. These last are very useful in photomicrography. For absolutely critical work **Gifford's gelatine and glass screen** can be fitted into the same ring. It consists of a disc of green glass and a gelatine film, and gives approximately monochromatic light, though with considerable loss of light. It is, however, inexpensive. The most perfect method, other than by the use of a costly prism arrangement, is **Gifford's fluid monochromatic light screen,** containing a slip of optically worked, blue-green glass in a trough filled with a medium composed of aniline green and glycerine. This passes blue-green rays only, in the F portion of the spectrum, the red rays being completely absorbed, and does

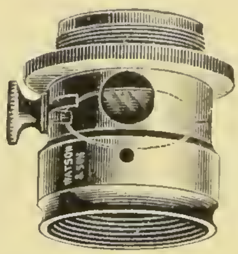

FIG. 48.—VERTICAL ILLUMINATOR.

not reduce the illumination so much as the gelatine and glass screen.

Nosepieces.—A very useful accessory is a **nosepiece,** though it has the drawback that it generally still further decentres the axis of the objectives from the axis of the microscope tube, necessitating recentring of the condenser with each rotation of a new objective into place. Zeiss makes an ingenious objective changer, into which each objective slides independently on its own carrier, and which has centring adjustments, but it is cumbrous and costly. Otto Himmler, of Berlin, makes a noncentring objective changer, which is convenient, but tends

to throw the objectives out of line. Watson makes an ingenious nosepiece with expanding jaws to grip the screw of the objective. The rotating nosepieces are made to hold two, three, or even four objectives, and are now also made practically dust-tight. Four objectives, however, make a heavy weight for a fine adjust-

FIG. 49.—DUSTPROOF TRIPLE NOSEPIECE.

ment to support, and the best form is the dustproof triple nosepiece (Fig. 49), made in aluminium.

Micrometric Apparatus.—Some means of measuring objects is sooner or later necessary to the microscopist. The simplest means is that of a **stage micrometer** (Fig. 50), graduated in $\frac{1}{100}$ and $\frac{1}{1000}$ of an inch, or

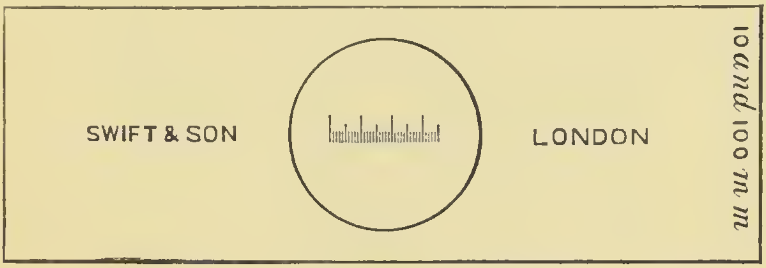

FIG. 50.—STAGE MICROMETER.

$\frac{1}{10}$ and $\frac{1}{100}$ of a millimetre, whilst a small disc drops into the Huyghenian eyepiece, and lies just upon the diaphragm so as to be in the focus of the eye-lens. This latter is known as the **eyepiece micrometer** (Fig. 51), and is also ruled with divisions, generally bearing some relation

to an inch or millimetre scale. Sometimes the eyepiece micrometer is fitted to a plate running through the eyepiece, and adjustable by means of a screw for convenience in getting exact alignment. The most elaborate form is the **Screw micrometer eyepiece** (Fig. 52), which

FIG. 51.—EYEPIECE MICROMETER.

is a beautifully accurate piece of workmanship, by means of which, in skilled hands, the $\frac{1}{100000}$ of an inch can be spanned. It is a Huyghenian eyepiece, with a movable and a fixed wire set in the focus of the

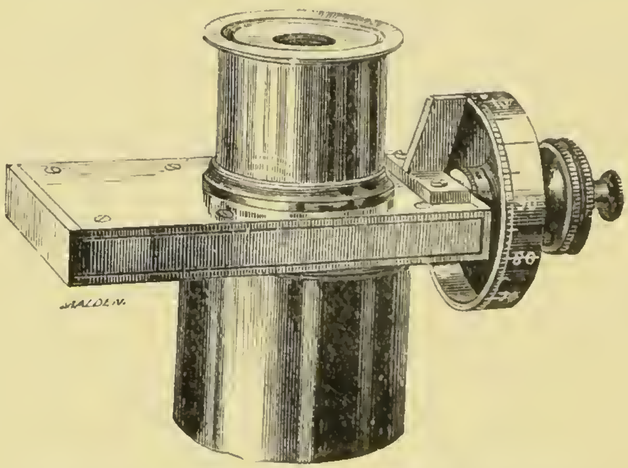

FIG. 52.—SCREW MICROMETER EYEPIECE.

eye-lens. The movable wire travels across the field by motion derived from a milled head and graduated drum. The latter is divided into $\frac{1}{100}$ parts. Within the eyepiece, in view of the eye-lens, but set to one side, a sort of toothed comb is placed as a guide, one revolution of

the external milled head causing the movable wire to travel from one tooth to another. Thus counting and measuring is facilitated.

Measuring.—To make measurements it is only necessary to note the number of arbitrary divisions in the eye-

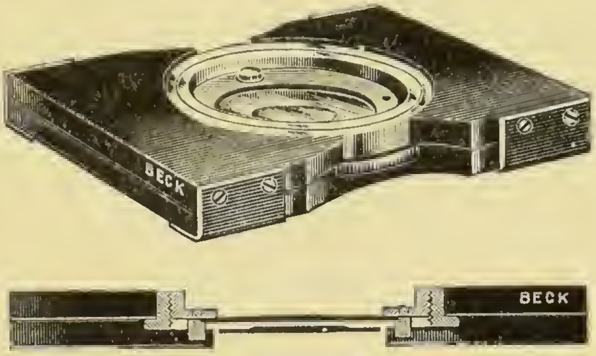

FIG. 53.—BECK'S COMPRESSOR.

piece micrometer which correspond with the object to be measured, then to replace the object by the stage micrometer, and note the exact measurements which correspond to those taken in the eyepiece.

Compressor.—**Stage Forceps** are sometimes useful, and

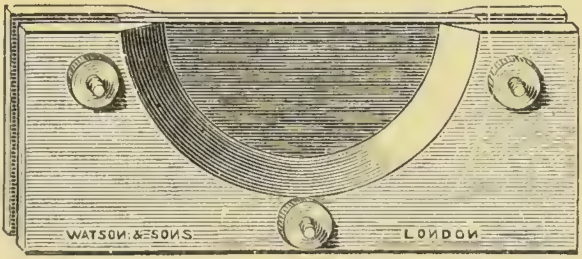

FIG. 54.—BOTTERILL'S TROUGH.

a **compressor** is often of service, such as Beck's form (Fig. 53), which is parallel, and easily cleaned, whilst broken glasses are readily replaced. A glass trough is a handy stage accessory, especially for pond-hunters, and perhaps the best form is Botterill's (Fig. 54), composed

of two slips of glass separated by an ordinary indiarubber ring, and held between two vulcanite plates, the whole being retained in position by three screws. The glasses can be easily cleaned or replaced.

Drawing Apparatus.—It is quite practicable to make good drawings direct from the microscope when used

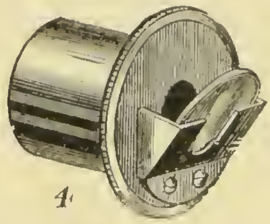

FIG. 55.—BEALE'S NEUTRAL TINT REFLECTOR.

in the ordinary way, the paper being placed as near the stand as possible ; but for accurate work some form of camera lucida is necessary.

Beale's Reflector.—The cheapest and perhaps the easiest to use is **Beale's neutral tint reflector** (Fig. 55).

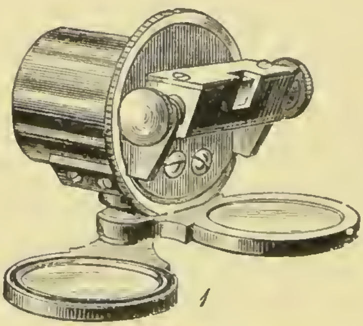

FIG. 56.—WOLLASTON'S CAMERA LUCIDA.

It is simply a disc of tinted glass placed above the eyepiece at an angle of 45 degrees to the optic axis. To use it, however, the microscope must be placed in the horizontal position, which is not always possible. The eye is placed above the glass disc, and looks down

through it on the drawing-paper placed beneath. The microscopical image can then be readily traced. It is, however, transposed, though not inverted.

Wollaston's Camera Lucida.—Wollaston's Camera Lucida (Fig. 56) was very popular once, but is now little used. Like Beale's form, it necessitates the microscope being placed in the horizontal position. Its principle is that of a prism above the eye-lens reflecting the microscope image into the eye, but only half the pupil of the eye looks at this image, the other half looking down upon the drawing-paper. The least variation in position of

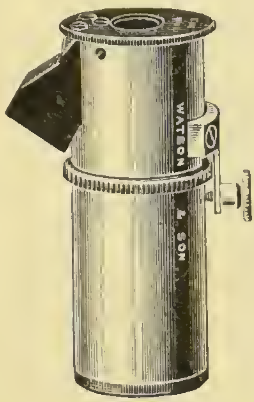

FIG. 57.—COMBINED EYEPIECE AND CAMERA LUCIDA.

the eye makes one image much more distinct than the other, and it is altogether not an easy instrument to use.

Combined Eyepiece and Camera Lucida.—A very useful and convenient eyepiece and camera lucida combined is sold by most opticians (Fig. 57). A prism reflects the drawing-paper and pencil into the eye through a second silvered prism, which has a central aperture through which the microscope image is viewed direct, and it can be used with the microscope in a vertical or inclined position. In the latter case, however, the paper must be inclined on a drawing-board, so as to be parallel with the

object on the stage; otherwise there will be distortion of the drawing.

Abbe Camera Lucida.—The Abbe form is really an elaborated form of the preceding camera lucida, but it is the best and easiest to use (Fig. 58). It reflects the paper by means of a mirror of some size, which is attached to an arm projecting from a ring surrounding the eyepiece. Above the latter is a silvered prism again reflecting the image of the paper and pencil into the

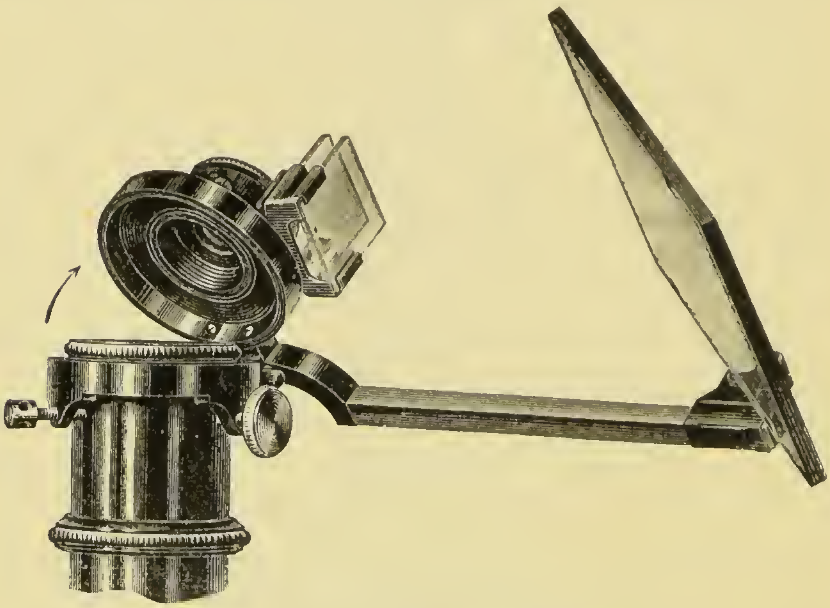

Fig. 58.—Abbe Camera Lucida.

eye, the prism, as in the former type, having a small, clear space in its centre through which to view the microscope image. In its completest form the silvered prism above the eyepiece is provided with centring adjustments, and can be readily swung out of the way; and it is also provided with two sets of smoked discs of graduated densities to adjust the light, one set being between the prism and the eyepiece, and the other set being between the prism and the mirror. By this means

the difficulty of adjusting the respective brightness of the two images is largely overcome.

Lamps.—The lamp used by microscopists is generally of paraffin, with a $\frac{1}{2}$-inch wick, and it need not necessarily be other than the ordinary lamp, which can be bought anywhere for a shilling or two, and for which a cardboard screen with an aperture cut in it can easily be made at home.

The excellent and often elaborately fitted microscope lamps sold by opticians are, however, very useful. Their great convenience lies in the readiness with which they may be raised or lowered, and the flat receptacle for the oil which enables them to be brought close to the table. If a regular microscope lamp be purchased, it should certainly have this form, and the reservoir should be capable of rotation, so as to enable either the flat or the edge of the flame to be used. It should also have an iron chimney, holding an ordinary 3-inch by 1-inch glass slide, which can be readily and easily exchanged if cracked. A reflector is worse than useless, as it confuses the light rays. This type of lamp is shown in Fig. 59. Vertical and horizontal adjustments by rack and pinion are refinements only necessary for a limited class of work, requiring the utmost nicety of adjustment, but an attachment for an aplanatic bull's-eye of the Herschel or Nelson type is often of much service, especially in photography. Beck makes a most convenient lamp of this sort, with the bull's-eye swinging up and down, so that the flame always remains central. A flat receptacle for the oil, as already mentioned, is really essential, in order that the flame may come within 3 inches or so of the table, and this is, consequently, a primary requirement.

Heliostat.—The **Heliostat,** apart from its cost, has too

manifest disadvantages in this country to be much used, and electric and incandescent gas-lamps, though handy, are not suitable for critical work. For photography an oil lamp or an acetylene burner may be used, but in many cases the oxy-hydrogen light or the electric arc light are required.

Davis Shutter.—A '**Davis Shutter**' is merely an iris

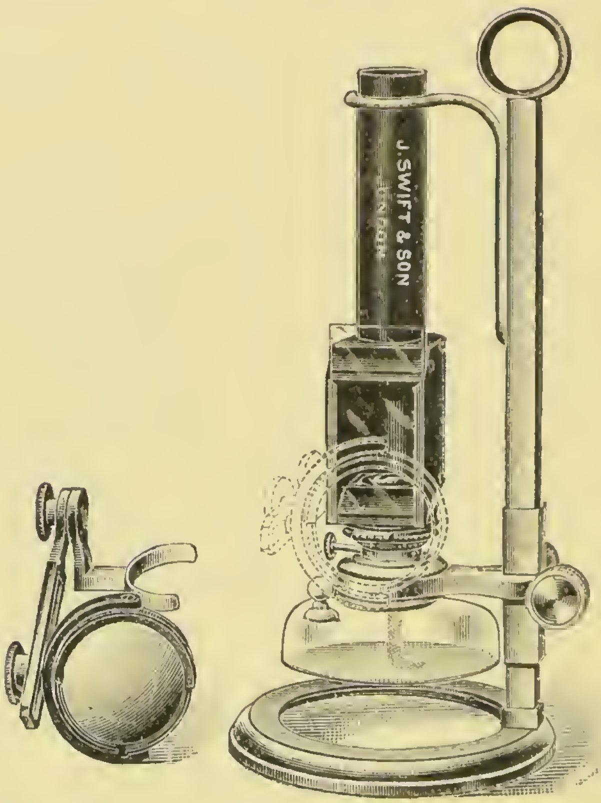

FIG. 59.—MICROSCOPE LAMP.

diaphragm mounted in a ring so as to screw above the objective. It is useful in photography as a means of cutting off flare at the sides of the tube, and, as it reduces the aperture of the objective, it is also sometimes of service in increasing the 'penetration' or depth of focus,

though, of course, at the expense of the definition. If a carrier to fit into the sub-stage be provided, the Davis shutter, being fitted with the Society's screw, enables a low-power objective to be used as a condenser, and provides an efficient iris diaphragm.

CHAPTER VI

THE PRACTICAL OPTICS OF THE MICROSCOPE

It is unnecessary here to give a detailed explanation of the principles underlying the use of lenses, and the formation of real and virtual images. Under any circumstances the treatment would necessarily be inadequate within the limits of space at our disposal, but the beginner will find it to his advantage to consult some elementary work on physical optics, or one of the larger books dealing with the microscope, in order to obtain a clear idea of the subject. For the understanding, however, of many matters connected with the microscope it is necessary to bear in mind the cardinal fact that a lens is in reality but an assemblage of superposed prisms, and that light in passing through a lens is accordingly *refracted*, *deviated*, and *dispersed*.

Refraction.—The **Angle of Refraction** is dependent upon the fact that a ray of light passing into a denser medium is refracted or bent *towards* the perpendicular, and that a similar ray of light passing into a rarer medium is, conversely, bent *from* the perpendicular. This is illustrated in Fig. 60, where A is the incident ray in air which, entering the block of glass represented by the shaded lines, is refracted *towards* the perpendicular or 'normal' D, as represented at B, and emerging again into a rarer medium, is again refracted *from* the perpendicular at C. In A and B

we have refraction, and in A and C lateral displacement due to refraction. The amount of refraction will vary according to the respective densities of the media, but will remain constant in the relation any two media bear to each other, and the *ratio* of refraction in the same medium will be the same, whatever may be the angle of incidence. Taking air, therefore, as unity, it is easy to calculate the amount of refraction all other substances bear to air, and, by dividing the sine of the angle that the incident ray makes with the perpendicular by the sine of the angle that the refracted ray makes with the perpendicular, to arrive at the *refractive index*.

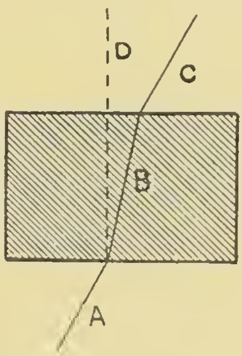

FIG. 60.—REFRACTION OF LIGHT.

Refractive Index.—Thus calculated, the refractive index of water may be taken as 1·334, of cedar oil as 1·510, of Canada balsam as 1·526, of fluor spar as 1·4338, of crown glass as 1·51 to 1·56, of flint glass as 1·54 to 1·71, and of realgar as 2·549.* It must be borne in mind, however, that whilst, as already stated, the ratio of refraction remains the same in any one medium, whatever the angle of incidence, yet this very fact involves an increasing amount of inclination the greater the angle the incident ray makes with the perpendicular, until we

* Carpenter, 8th edit., pp. 1108, 1109.

arrive at a *critical angle* when the refracted ray cannot emerge from the denser medium to which its refraction is due. It is consequently totally reflected back at the same angle. This is readily demonstrated by holding a glass of water above the eye so that the surface looked at from beneath appears to be of mirror-like brightness. The critical angle of water, measured from the perpendicular, is about 48½ degrees, and of glass about 40½ degrees.

Deviation.—The **Angle of Deviation** is dependent upon the fact that an incident ray entering a prism is, in accordance with the foregoing law, refracted towards the perpendicular, but the sides of the prism being inclined towards each other, the perpendiculars vary for the two sides, and the ray on emergence is therefore again refracted, and in consequence deviated still further in the same direction. Fig. 61 shows this clearly, where A′A is the incident ray which is refracted at B towards the perpendicular D, but emerges at C refracted away from the new perpendicular D′.

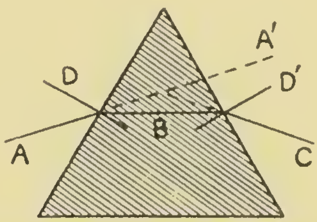

FIG. 61.—REFRACTION OF LIGHT THROUGH A PRISM.

It is scarcely necessary to add that upon the amount of deviation of the rays of light by a lens depends the focal length and consequent magnifying power of the latter.

Dispersion.—The **Dispersion** is dependent upon the fact that, as white light is composed of rays of different wave-lengths and of different colours, the shorter waves

are more refracted than the longer waves in passing through a prism, and in consequence the resulting ray of light will be fanned out into a *spectrum*, of which the violet rays will be the most and the red rays the least refracted. This is purposely not represented in Fig. 61.

The practical application of the foregoing explanations will be evident on referring to Figs. 62 and 63, which represent the passage of two rays of light through a double convex and a double concave lens respectively. In the convex lens (Fig. 62) parallel rays of light fall upon the surface of the lens, whose curvature gives varying normals, with the result that the rays converge

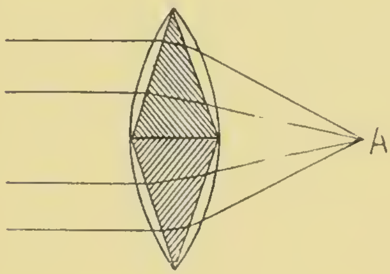

Fig. 62.—Refraction of Light in Double Convex Lens.

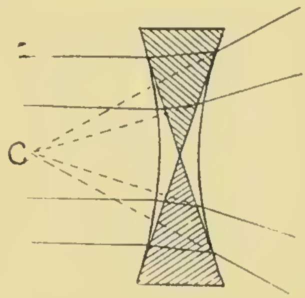

Fig. 63.—Refraction of Light in Double Concave Lens.

to a 'real' focus at A. In the concave lens (Fig. 63) the opposite happens, and the rays diverge as if they diverged from a point, C, on the anterior side of the lens, called the 'virtual' focus. In the convex lens the focus A, formed by the parallel rays of light, is spoken of as the 'principal focus' or 'focal point,' and in a simple lens of this description the 'focal length' will be the distance from A to the centre of the lens. If, on the other hand, the radiant were placed at A, a parallel beam of light would be given off from the other side of the lens. If the radiant were placed nearer to the lens than A, a divergent beam would be given off,

whilst if it were placed beyond A, a converging beam would result, coming to a focus, which is spoken of as a 'conjugate focus.' Fig. 64 illustrates various types of lenses.

Magnification.—The magnifying power, or the con-

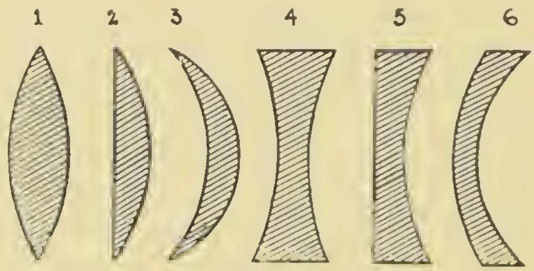

Fig. 64.—Types of Lenses.

1. Bi-convex; 2. Plano-convex; 3. Converging meniscus; 4. Bi-concave; 5. Plano-concave; 6. Diverging meniscus.

verse, depends upon the spherical curves of the lens or their distance from the centres of curvature—*i.e.*, the 'radii'—combined with the direction of the rays of light. Primarily, a double convex lens, with a radius of 1 inch,

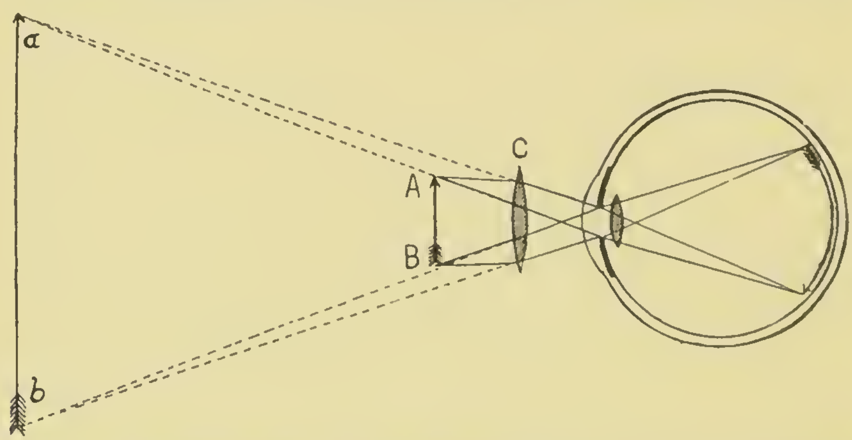

Fig. 65.—Magnification, and Formation of a 'Virtual' Image.

will have a focus of 1 inch, whilst a plano-convex lens will of, course, have a focus of twice that amount—*i.e.*, 2 inches. The effect of the convergence can be seen by reference to Fig. 65, where conjugate foci are set up,

with the result that the rays from the image A, B are converged by the lens C so as to enter the eye as parallel or slightly divergent rays, this being necessary for focussing upon the retina. The image is normally *seen* at a distance of about 10 inches from the eye, the rays forming a virtual image at *a b*. We will speak later of the determination of the magnifying power of a lens, but in the meantime it is necessary to note that the actual magnification at *a b* with any specific lens will depend with each observer upon whether his eye is able to focus the object so as to give a virtual image at a distance of about 10 inches from the eye. If the eye be short-sighted, and the image be found at, say, 7 inches, it will be apparent that the magnification through a lens will be only seven-tenths of that obtained by the normal eye, whilst the converse applies to the long-sighted observer.

Aberrations.—There are two important defects inherent in a simple lens, and, indeed, to a less extent in all compound systems of lenses hitherto constructed. These are known respectively as **spherical** and **chromatic aberration.** The rays of light passing through the margin of a lens, however carefully made, do not, unfortunately, come to a focus in exactly the same place as the rays passing through the central part. The double convex lens is one of the worst offenders in this respect, whilst the plano-convex lens is generally less imperfect, provided the most favourable position is selected. This will be understood by reference to Figs. 66 and 67. In Fig. 66 the marginal rays come to a focus nearer the lens than the more central rays, a state of affairs known as 'under-correction,' whilst in Fig. 67 the central rays come to a focus nearer the lens than the marginal rays, which is known as 'over-correction.' In the cheapest lenses

this is made less evident by shutting off the marginal rays by means of a diaphragm, with consequent loss of light and reduction of aperture, upon which 'resolving power' so largely depends. In higher-class lenses the spherical aberration is reduced by combining lenses of varying curvatures which are composed of glasses of

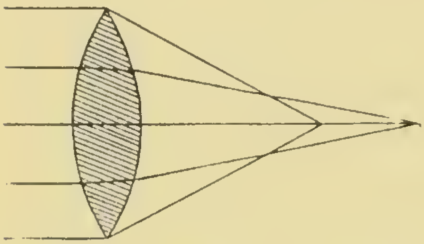

FIG. 66.—SPHERICAL ABERRATION (UNDER-CORRECTION).

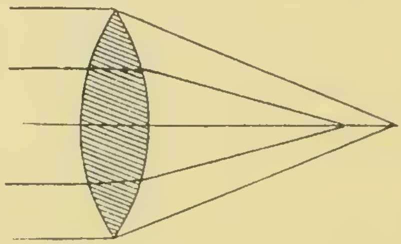

FIG. 67.—SPHERICAL ABERRATION (OVER-CORRECTION).

different densities, the eyepiece also doing its share of the corrections, especially in the apochromatic systems. The correction of the spherical aberration is known as **aplanatism.** In addition to this, the lens *disperses* the light, as explained on p. 102, the amount of dispersion varying according to the refracting angle of the lens and

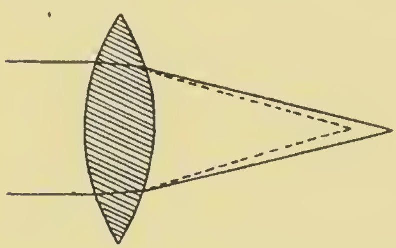

FIG. 68.—CHROMATIC ABERRATION (CONVEX LENS).

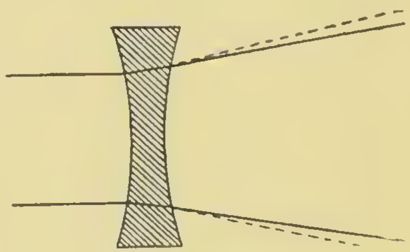

FIG. 69.—CHROMATIC ABERRATION (CONCAVE LENS).

the refractive power of the glass of which it is composed, so that the violet rays at one end and the red rays at the other end of the spectrum are brought to a focus independently of each other at different distances from the lens. This is known as **chromatic aberration.** Figs. 68 and 69 represent a convex and a concave lens

respectively, the dotted line representing the violet or most refracted ray, and the black line the red or least refracted ray. One prism can be made to correct another, as in Fig. 70, but only by destroying the refraction, and the remedy is, therefore, to combine two lenses made of glass of different refraction, but corrective dispersion—for instance, a crown and a flint glass, as represented in Fig. 71—so as to neutralize the dispersion without destroying the refraction. This is known as **achromatism.**

Irrationality of Spectrum.—Unfortunately, there is a further difficulty to be overcome owing to the fact that the ratio of dispersion in a prism or lens is not the

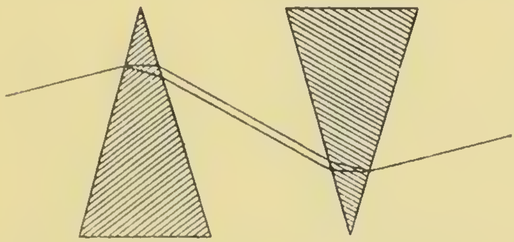

FIG. 70.—CORRECTION OF DISPERSION BY PRISMS.

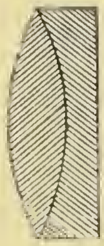

FIG. 71.—ACHROMATIC COMBINATION.

same for all, or, indeed, any, of the colours of the resulting spectrum, and that no two glasses of different refractive indices, but proportional dispersion, can be obtained. This is known as the 'irrationality of the spectrum.' It will be seen that the optician has, therefore, no easy task in endeavouring to correct both spherical and chromatic aberration, and the colour left outstanding in an achromatic combination in which two colours have been successfully combined is known as the 'secondary spectrum,' a not too happy denomination. It may be added that the colours thus in practice combined are those which have the greatest light intensity, the

spherical aberrations being corrected for the yellow-green portion of the spectrum, whilst the chromatic aberrations are corrected for the orange-yellow and green-blue portions.

Jena Glass.—These corrections have been greatly facilitated in recent years by the researches of Professor Abbe, in conjunction with Dr. Schott, and the resources of the well-known glass-works of Schott and Co., and the optical firm of Carl Zeiss, both of Jena. For this purpose the German Government made a substantial grant of money, and the result has more than justified the expenditure, providing a notable object-lesson to other countries. Professor Abbe and his *confrères* succeeded in producing new forms of optical glass, and in constructing new lenses, which have become famous throughout the world, and the prestige thus given to the firm of Carl Zeiss has given them an enviable position in the manufacture, not only of these lenses, but in optical apparatus of all kinds. The 'Schott' or 'Jena' glasses are now used by all leading opticians both in this country and abroad, and the further improvement in achromatic lenses is sufficiently marked to justify their description as 'semi-apochromatic,' for they closely rival the 'apochromatic' lenses of Zeiss, Powell and Lealand, and other makers. The respective merits and advantages of these lenses have been already dealt with, but we may explain here that in the apochromatic objectives Professor Abbe, by means of original formulæ and the combination of new glasses (notably those containing fluorite) of varying refractive and dispersive properties, succeeded in entirely eliminating the secondary spectrum, and thus uniting *three* different colours of the spectrum in one point of the axis, whilst at the same time correcting the spherical

aberration for two different colours, and therefore practically for all, in contradistinction to the usual correction for one colour in the brightest portion of the spectrum only.

Disturbance of Corrections by Cover-Glass.—The thickness of the cover-glass over an object has an important influence upon the corrections of an objective. In Fig. 72 the rays of light emanating from an object at A are refracted towards the perpendicular on entering the denser medium of the cover-glass B, according to their angle of incidence, and on emergence their direction is so altered that a condition of under-correction, as in

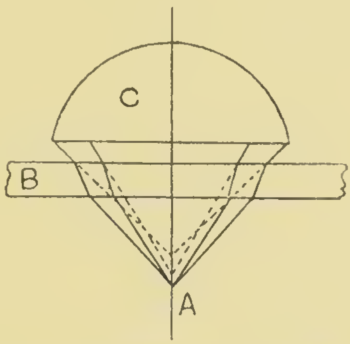

FIG. 72.—INFLUENCE OF COVER-GLASS.

Fig. 66, results, this being shown in Fig. 72 by the dotted lines. The result is that over-correction is set up in the objective. To remedy this, the objective, when used under such circumstances, must itself be under-corrected. It will be apparent, therefore, that the corrections of an objective will be altered not only for uncovered, as compared with covered, objects, but also for cover-glasses of varying thicknesses. A thicker cover, for instance, requires to be met by a corresponding amount of increased under-correction in the objective, whilst a thinner cover requires over-correction. This

necessary under-correction of the objective is obtained by bringing the lenses closer together, and high-power objectives of the best quality are generally provided with a rotating collar, which enables the distance between the combinations of the objectives to be adjusted for variations of cover-glass. A very general method is to shorten or lengthen the microscope tube, which has the same effect. Thus, supposing the objective to be corrected for a cover-glass 0·008 inch thick, it would be necessary to shorten the tube—*i.e.*, decrease the distance between eyepiece and objective—if a thicker glass were used, or to lengthen it for a thinner glass. By so doing we should, of course, also alter the magnification. With a correction collar we should close the lenses of the objective for a thicker cover, and open them for a thinner one.

The correction of objectives by either of the above means requires considerable practice if the best results are to be obtained—results which the eye sometimes needs educating to perceive.

It would be a great convenience if makers would adopt one uniform thickness of cover-glass to which all objectives could be corrected, or if the Royal Microscopical Society could standardize a definite thickness. One well-known maker corrects for a cover-glass 0·006 inch thick, whilst another corrects for a 0·008 inch cover-glass.

Objectives are likewise corrected for a certain definite tube-length, and it will scarcely be necessary to point out, after what we have previously said, that an objective corrected for a certain length of tube cannot be used critically for any other length of tube, except as mentioned above. This, whilst showing the advantage of having a draw-tube, shows also the

limitations of variation of magnification by the simple device (sometimes suggested) of drawing out or closing up the draw-tube. The standard English tube-length is 10 inches, but there seems to be an increasing tendency among English opticians of repute to correct their objectives for the short Continental tube-length. We regret this for many reasons, one of which is that an objective corrected for the 10-inch tube performs better on a 6-inch tube, if necessary, than in the reverse case, and also for the reason that it is better to obtain a given magnification by using a 10-inch tube, and keeping the power of the eyepiece as low as possible. But we especially protest against the practice of certain makers of quoting their objectives as giving certain magnifications calculated for a 10-inch tube, but refraining from adding the necessary qualification that the said objectives are in reality corrected for the 6-inch tube only. It would be a great advantage if makers would mark upon their objectives, as one or two firms already do, not only the N.A. and the actual focal length of the objectives, but also the tube-length for which they are corrected. The Continental system of designating objectives by arbitrary letters or numbers has nothing in its favour.

Dry and Immersion Lenses.—It will be seen that the dry lens used in air is subject to many disturbing influences which react unfavourably upon its performance, and this is especially noticeable with high powers, such as a $\frac{1}{8}$-inch, and particularly when used with high-power oculars. Owing to the refraction of the rays when entering the air-space between the cover-glass and the objective, a considerable proportion of them fail to enter the latter, and accordingly objectives have been specially constructed and corrected for use when

immersed in a medium placed between the objective and the cover-glass. It will be manifest that for contact to be maintained such objectives must have a comparatively short working distance, and **immersion lenses,** as they are called, are therefore always high-power lenses, generally $\frac{1}{8}$-inch or $\frac{1}{12}$-inch. The medium may be water, oil, or, in the case of one exceptional and costly lens, mono-bromide of naphthalin. Whilst a water-immersion lens gives much better results than a dry lens, it is inferior in performance to an oil-immersion lens. The oil universally used is cedar-wood oil, which has a refractive index practically the same as crown glass—*i.e.*, 1·52, so that the cover-glass becomes to all intents and purposes part of the objective. This is accordingly spoken of as a **homogeneous immersion lens.** The refractive index of water is 1·334, air being taken as 1·0. With a homogeneous lens there is little or no disturbance due to variation in thickness of cover-glass, and no need, accordingly, for a correction collar.* But the most important point is that, owing to the fact that none of the rays of light emanating from the object are subject to diffraction, and are thus bent out of their course, an oil-immersion lens utilizes a larger number of rays than a water-immersion, and a much larger number of rays than a dry lens. Moreover, these rays are those which have most value, the intensity of the emitted rays becoming less as they form a larger angle with the perpendicular. As a matter of fact, an oil-immersion lens with an angular aperture of 82 degrees receives an equal number of rays to a water-immersion

* Messrs. Powell and Lealand fit some of their homogeneous immersion lenses with correction collars, with a view to gaining the very best results under all conditions—such as may be caused, for instance, by mounting media of different refractive indices.

with an angle of 97 degrees, or a dry lens with an angle of 180 degrees, could so large an angle be obtained. Water-immersion lenses are not often used now except for objects that would be harmed by oil.

Angular Aperture.—The **Angular Aperture** of a lens is the extreme angle of the rays diverging from the object which can enter the objective. The mere diameter of the front or back lens of an objective is not understood by the term 'aperture'—in fact, it generally happens that the 'aperture' is in an inverse proportion to the diameters of various lenses. But, owing to the introduction of immersion lenses, it is apparent that the mere statement of angular aperture does not express the relation that different lenses, say a dry and an immersion lens, bear to each other. Professor Abbe, to whom modern microscopy owes so much, introduced in 1873 a formula to which all systems can be referred for comparison, and which represents the ratio between the radius of the *effective* aperture on the side where the image is formed—*i.e.*, at the back instead of the front of the objective—and the equivalent focal length of the objective. This resolves itself mathematically into the sine of half the angle of aperture multiplied by the refractive index of the medium between the front of the objective and the cover-glass. The formula is. therefore, n sine u = N.A.—n being the refractive index, sine u the sine of half the angle of aperture measured at the back of the lens, and N.A. the **numerical aperture.** This last term has now come into general use. The *Journal of the Royal Microscopical Society* contains a table in which the various values have been calculated out, and to which reference may be made (see Appendix, p. 170, Aperture Table).

Rating of Objectives.—It may be as well to repeat

here that the terms 1 inch, $\frac{1}{4}$ inch, etc., do not represent the distance between the under side of the lens and the object. The tendency of the day is to increase the aperture, bringing the lenses closer and closer to the object, and the designations referred to may be taken practically as representing approximate magnifying power. A combination of lenses making up an objective of 1-inch power is treated as having an *equivalent focus* to an objective containing only a single lens with a radius of 1 inch on both sides and a consequent focus of 1 inch. Such a lens, when focussed upon an object, will give a real image upon a cardboard screen placed 10 inches from its upper principal focal plane of ten times the actual size of the object. Ten inches is assumed to be the normal visual distance, and taking the inch, therefore, as a standard, we may say that without any eyepiece it gives in a 10-inch tube a magnifying power of approximately 10 diameters. A $\frac{1}{4}$-inch gives 40 diameters, a $\frac{1}{6}$-inch 60 diameters, and so on. To get the actual magnification of a microscope, we must know not only the length of the tube, but the magnifying power of the eyepiece in addition. Fig. 73 shows the path of the rays in a compound microscope. The rays of light from the object A, upon which the objective is focussed, pass through the objective B, and, crossing the rays from the other side, would, if uninterfered with, form a real image beyond the position of the diaphragm D. But the eyepiece is so constructed that the field-lens C intercepts the rays shortly before they reach the position necessary to form such a real image, and bends them in, forming the real image in the air in the position defined by the diaphragm D. This image is again magnified by the eye-lens E, a magnified virtual image being projected at F, G in the same way as explained on p. 104, by means of Fig. 65.

Effect of Tube-Length on Magnification.—It is evident from what has been said that the initial magnification of an objective will vary according to the distance of D from the objective, this being the position where the real image is focussed; and if the microscope tube be shortened or lengthened, not only will refocussing be

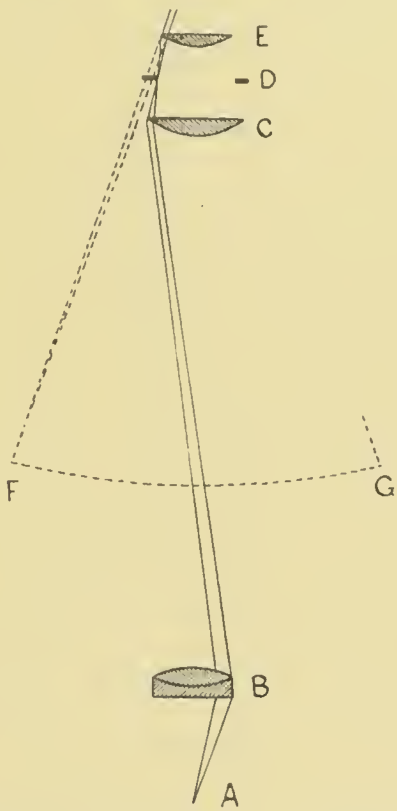

FIG. 73.—DIRECTION OF LIGHT IN A COMPOUND MICROSCOPE.

found necessary, but the magnification will vary proportionately. If the eyepiece magnifies six times, then an inch objective with this eyepiece and a 10-inch tube will give a total magnification of 60 diameters, a $\frac{1}{4}$-inch will magnify 240 diameters, and so on. With a 6-inch tube the magnification will be only six-tenths

of the foregoing, and this must be carefully borne in mind. We may repeat the necessary qualification that the frequently met with instructions as to varying the magnification by altering the tube-length are not practicable for critical work with objectives of high or even moderate aperture; an objective must be used with the tube-length for which it has been corrected, due allowance being made for thickness of cover-glass, as before explained.

Opticians have, unfortunately, a tendency to give their objectives rather larger magnifications than those we have mentioned, owing partly to the difficulty of making low-power objectives of as wide apertures as the taste of the day demands, and this should be noted when purchasing. It is easier to make high-power objectives of a given large aperture than low-power ones. The higher the aperture, the better should be the definition, but the higher also is the price, and there is the additional disadvantage to many workers that anything out of the exact plane in focus is practically invisible. Most workers use objectives of both high and low aperture, and each have their advantages.

Magnification of Objectives—Initial Magnification.—The easiest way to test this is by the method mentioned in Carpenter. A micrometer slide, ruled in hundredths and thousandths of an inch, or in tenths and hundredths of a millimetre, is placed upon the stage of he microscope, and the latter inclined to the horizontal position. A strong light is transmitted through the microscope, and the room darkened. The micrometer lines are then focussed sharply upon a piece of white cardboard placed 5 feet (60 inches) behind the front lens of the objective. The divisions on the screen are measured with an ordinary foot or millimetre rule, and the result

divided by six, which gives, of course, their size at 10 inches from the objective. The value of the original stage micrometer divisions being known definitely beforehand, it is easy to calculate the resulting magnification. Suppose the distance between micrometer rulings of two $\frac{1}{100}$ parts of an inch to measure $\frac{1}{4}$ inch at 5 feet distance, with a nominal 1-inch objective, then at 10 inches distance they would measure 0·2083 inch, which is equivalent to an initial magnification of nearly ten and a half times. A millimetre scale or rule can be used on the basis of 25·4 millimetres to the inch. Magnifications are always expressed in diameters or *linear* measurements, not in areas. A considerable distance such as the above is taken in order to reduce the amount of error due to the fact that the measurements should really be taken from the principal posterior focus of the objective, which in a compound system cannot easily be found. But by measuring from the front lens as above a very small margin of error is left. It is best to take the mean of several micrometer divisions, as they are not quite accurately ruled.

Combined Magnification.—Combined Magnification of eyepiece and objective is calculated by a similar method, except that there is not the same necessity for taking a longer distance, and the image of the micrometer must be accurately projected exactly 10 inches from the eye-lens of the eyepiece. This may be done either direct by means of a photo-micrographic camera or otherwise, or at right angles, by means of a Beale's camera lucida (see p. 94), to a piece of paper placed on the table, the microscope being raised, if necessary, to the requisite height so as to get the exact distance of 10 inches. Short-sighted observers may therefore need to use spectacles for this method. The magnifi-

cation as seen by such observers when looking through the microscope will, of course, be less than that calculated by the above methods, as explained on p. 105: in fact, an observer who formed his image at 5 instead of the normal 10 inches from the eye would only *see* objects at half the magnification seen by ordinary observers, on which the foregoing calculations are based.

Magnification of Oculars.—The **Eyepiece Magnification** is readily calculated by dividing the combined magnification by the initial magnification of the objective independently determined. We may remind the reader, as explained earlier (p. 115), that the eyepiece magnification remains constant, but that if the tube be less than the normal 10 inches in length the initial magnification will be proportionately less, and the combined magnification will vary accordingly.

Numerical Aperture.—The **Numerical Aperture** is best measured by means of Abbe's apertometer. It is a plate of glass ½ inch in thickness, and rather more than semicircular in shape. The straight edge is bevelled underneath to an angle of 45 degrees, so as to eflect the light through a small aperture in a silver disc placed at the centre of the semicircle. The latter is graduated on the edge with the requisite numerical apertures and the equivalent angular apertures in air, and round the semicircle slide two metal discs to act as indicators. The points of these latter are easiest read when directed inwards for objectives below 0·7 N.A. and outwards for higher apertures. In use the apertometer is placed upon the stage, and the aperture in the silver disc focussed with the objective to be tested, the aperture being made as central as possible, and the tube-length of the microscope being that for which the objective is corrected by the makers. The flame of a

lamp is placed opposite and level with the apertometer. Any eyepiece can be used. Without altering the adjustments, the draw-tube is then unscrewed, and a low-power auxiliary objective supplied with the apparatus is screwed into the universal screw generally found at the bottom of the draw-tube. The draw-tube and eyepiece are replaced, and this auxiliary objective is then focussed by means of the draw-tube upon the back of the objective to be tested, so that the images of the indices before mentioned are clear and distinct. The appearance, if the lamp be properly adjusted—for which purpose it may be necessary to move it first to one side and then the other—is that of a band of light across the field. As the indices are moved round the semicircular glass plate, and in close contact with it, their points will be seen on this band of light, and they are to be moved until these points just touch the edge of the luminous band, where it passes beyond the field of the objective. It is best to adjust the draw-tube so that the points of the indices and the back of the objective appear equally distinct. The readings are taken from the upper edges of the indices, corresponding to the points, and their mean gives the requisite numerical or angular aperture. With microscopes of the Continental size of tube it is necessary to use a low-power eyepiece without any diaphragm between the eye and field lenses, otherwise the field of the latter may be too small to enable the whole of the back lens of a wide-angled objective to be taken in. Though the apertometer is not difficult to use, it requires some practice before its readings can be relied upon as a true test of the N.A. of an objective, owing mainly to the difficulty of knowing when the points of the indices and the edge of the aperture of the objective are in actual alignment.

Penetration.—Penetration in an objective is the power of seeing deeper into an object than the exact plane nominally in focus. It will be apparent that it is the converse of both aperture and power, being inversely proportional to the former, and it is also dependent upon the size of the cone of illumination. The lower the power and the lower the N.A., the greater will be the penetration, but at the expense of the resolution. A convenient way of increasing the penetration of an objective is by placing an iris diaphragm immediately behind it and so reducing the aperture (see p. 98).

Illuminating Power.—Illuminating Power, or brightness of image, other things being equal, increases as the square of the N.A. The increased amount of light due to a sub-stage condenser, or to different sources of illumination, are, of course, other factors altogether.

Flatness of Field.—Flatness of Field varies much with different objectives, and perfect flatness of field is not obtainable with our present wide-angled objectives, owing to unavoidable spherical aberrations still outstanding. In practice it means that an object is not in focus as it approaches the margin of the field of view. A spine of Echinus is often used as a test, but a micrometer slide is preferable, and it will be seen that when the centre is in focus the lines become more or less hazy, and even curved outwardly, as they approach the periphery. The estimation of flatness of field is largely a matter of comparison. We may add that the eyepiece may be responsible to a certain degree, but this is easily determined by changing objectives and eyepiece.

Definition.—Defining Power is generally distinguished from resolving power, the latter being treated as a fixed quantity theoretically dependent on the N.A., as before

explained, whilst the defining power is dependent upon the skill of the optician in calculating and making his lenses, upon the reduction of the spherical and chromatic aberrations, upon the exact centring of the lenses to their optic axis, and the accuracy with which they are placed at right angles with this same optic axis. One of the drawbacks incidental to the use of a correction collar is the difficulty in keeping in exact alignment the various lenses making up a combination. Defining power can only be decided by examining suitable test objects under critical conditions, and is a matter requiring much practice and experience. For suitable test objects see p. 142.

Working Distance.—Working Distance is the free space, whether of air, water, or oil, between the front lens of the objective, or its surrounding brasswork, and the cover-glass of the object. It generally decreases, as might be expected, with increase of aperture, but varies in different objectives of equal aperture according to the skill of the computer and optician. It is always much less than the focal distance of an objective. With high-power lenses it becomes an important consideration, and more so with dry objectives of $\frac{1}{8}$-inch and upwards than with immersion lenses. With a dry $\frac{1}{6}$-inch objective of fairly high aperture (say N.A. 0·85) the working distance may be about 0·4 millimetre; with a dry $\frac{1}{8}$-inch of the same aperture it may be 0·25 millimetre or 0·15 millimetre; whilst a $\frac{1}{12}$-inch of N.A. 1·25 might have a working distance of 0·2 millimetre. It will be seen that cover-glasses of moderate thickness only should be used for objects that may be required at any time to be examined with high powers, but we have had objectives submitted to us for examination that would not focus through cover-glasses of

even moderate thickness. If the milled head of the fine adjustment of the microscope is graduated, and the value of the screw known, the determination of the working distance of a high-power objective is an easy matter; it has only to be brought very carefully into contact with the cover-glass, and then raised until the object is in focus, the revolutions of the milled head being carefully noted, and the calculation made accordingly. Failing such knowledge of the pitch of the screw, a rough measurement can be gained by looking between the objective and cover-glass at a bright light, by using a carefully-made wedge, or even by measuring from temporary marks on the bearings in which the fine or coarse adjustment slides.

Diameter of Field—Size of Field.—This should be primarily dependent upon the power of the objective, irrespective of the aperture, but it is also qualified by the diameter and magnifying power of the eyepiece, and by the size of the diaphragm in the latter. One advantage of the English size of tube is the increased field given with low-power oculars, and the firm of Zeiss endeavours to overcome this difficulty, not by increasing the diameter of the tube, but by making special eyepieces to screw into the latter when the draw-tube is removed. Roughly speaking, an inch objective will have a field 3 millimetres in diameter, a $\frac{1}{2}$-inch will give a field about 1·5 millimetres, a $\frac{1}{6}$-inch about 0·5 millimetre, and a $\frac{1}{12}$-inch about 0·25 millimetre in diameter.

Resolution and Aperture.—According to Professor Abbe, the 'resolution' of an objective—that is, its power of dividing a certain number of fine lines per inch—is dependent upon the obliquity of the rays of light to the axis of the microscope, which in turn depends upon the aperture of the objective. The number of such lines

to an inch resolvable by a certain objective with axial illumination and mono-chromatic light is obtained by multiplying its N.A. by 80,000. For daylight multiply by 70,000. Add to this the fact that the normal eye can perceive about 200 lines to the inch, and we get a ratio of aperture to power on which to base our calculations. If we multiply twice the N.A. by the wave-frequency of the light used, we arrive at the number of lines theoretically resolvable by oblique light. It follows that there is no advantage in mere magnification without increase of aperture, provided the magnification is sufficient to enable the observer to *see* what is required. This explains the disuse of the old high-power lenses, such as $\frac{1}{25}$- and $\frac{1}{50}$-inch, which gave mere empty magnification without increase of aperture. The tendency of a beginner is to use high powers unnecessarily, but the practised worker invariably uses the lowest power that will show him clearly what he wishes to see.

Optical Index.—Mr. E. M. Nelson has suggested that a new standard should be adopted which would show the value of an objective both with regard to power and N.A., and that accordingly the N.A. should be multiplied by 1,000, and divided by the magnifying power of the objective, the result being entitled the 'optical index.' It would be well if the term could come into general use.

Theoretically, objectives should have 0·26 N.A. for each 100 diameters of combined magnification (that is, including the eyepiece), if they are to be capable of showing all that is theoretically possible, but in practice very much less than this suffices. Messrs. Beck, for instance, make most of their objectives of moderate aperture, not only because they are less expensive, but because they give more of what is known as 'penetration,' or the power of seeing more than lies in one

actual plane. Moreover, a high aperture reduces the working distance. The tendency of the day is, however, as has been already said, to insist on high apertures, and each maker tries to outdo his competitors in this respect. Our advice to beginners would be to content themselves with moderate apertures—at any rate at first—but, above all, to get objectives made by first-rate houses only. If of other than English make, see that the screw is of the Society gauge (see Appendix), though this is now well-nigh universally adopted.

Under- and Over-correction.—This can be estimated by examining a coarse, unstained object by either axial or oblique illumination. All achromatic objectives will give a certain fringe of colour, which is increased if the condenser be not properly centred. With axial illumination, if the objective be under-corrected, there will be a bluish fringe, which will be increased when it is slightly racked up out of focus, whilst there will be an orange fringe when it is racked within the focus. When the mirror is swung to one side there will be a blue fringe on the side to which the mirror is swung, and an orange fringe on the other side. Over-correction shows exactly opposite results with both methods.

Collar Correction.—Facility in the use of the correction-collar, in order to rectify errors due to under- or over-correction, set up by various thicknesses of cover-glass, as explained on p. 109, can be gained by observing the way in which the object comes in and out of focus. If the image seems to diffuse or expand evenly when the objective is thrown sharply but slightly out of focus, the corrections are rightly adjusted; but if there is more expansion when the object is outside the focus, there is spherical under-correction, which will necessitate opening the lenses—*i.e.*, moving the correction-collar

towards the zero mark. If the expansion is more evident when the object is within the focus, there is over-correction, and the lenses must be closed. The movement must, of course, be equal in both directions.

Aplanatic Aperture of Condenser.—It has already been stated (p. 82) that the true value of a condenser lies in its **aplanatic aperture**, and this may be approximately estimated as follows: An object mounted in Canada balsam is placed upon the stage of the microscope, and the objective being first focussed upon it, the condenser is then focussed as described on p. 129, using the edge of the lamp flame, and focussing it in the centre of the field. Without altering the adjustments the eyepiece is then removed, and on looking down the tube, if the whole of the back lens of the objective appears filled with unbroken light, the aplanatic cone of light transmitted by the condenser exceeds, or at least equals, the numerical aperture of the objective used. Within narrow limits a slight racking up of the condenser not infrequently assists the determination, but the appearance of two dark spots shows either that the condenser has been racked too high or that its aplanatic aperture is lower than that of the objective. In this case an objective of less aperture must be tried, or, in the converse, one of higher aperture.

CHAPTER VII

MANIPULATION OF THE MICROSCOPE AND ITS ACCESSORIES

It is necessary now to deal with the elementary management of the microscope and its accessories. The modern microscope has become an instrument of such exquisite precision that the beginner generally finds himself at the very outset in need of explanation and assistance in this respect. A clear understanding of what he is doing is necessary if he is to obtain the best results. In our medical and other laboratories too little attention is often given to these matters, and it follows, therefore, that the student is not really familiar with the use of his instrument, and obtains more or less imperfect results. The general use of the sub-stage condenser has revolutionized microscopy, and attention must be again called most strongly to the fact that the proper management of the illumination of the object is a matter requiring as much or even greater care and attention than the actual focussing of the objective itself. This last is comparatively a simple matter, save where corrections have to be made for different thicknesses of cover-glasses.

Setting up Microscope.—Let us assume that the reader has provided himself with a microscope fitted up in accordance with the rules and suggestions made in Chapter III. He will place his microscope on the table

before him, and incline it, if possible, at a comfortable angle for looking down the tube. Of course, there is a certain amount of work that can only be done with the microscope in a vertical position ; but when the object will admit of it, it is a great convenience and rest to the muscles of the neck if the microscope be slightly inclined. This is a point that makers of even the less expensive foreign microscopes are beginning to realize, as one by one the English improvements are being adopted on the Continent. It will be found that ordinary daylight, though perfectly suitable for low-power work, is unsuitable for high-power and *critical* work, and as we are setting up our microscope for critical work, we will deal with lamp-light illumination accordingly. The beginner need scarcely be warned that the use of direct sunlight is absolutely out of the question for visual purposes. The lamp will be probably an ordinary ½-inch paraffin lamp, with a shade, as already described, but without a reflector, as this last only succeeds in confusing the rays of light. Some workers place the lamp on the immediate left of the instrument, in order to obviate any glare into the eyes, but the position immediately opposite and in front has so many advantages in ease of manipulation that this position is generally preferred, with a cardboard shade interposed if required. The lamp will therefore be placed in the latter position, with its wick turned *edgeways* forward, the light being about 6 to 10 inches or thereabouts from the mirror. It is well to accustom one's self to these approximate distances, as high-power immersion condensers are adjusted, amongst other things, for light at a definite distance from their back lenses. It will be necessary to carefully observe at the outset that the flame is immediately opposite the centre of the stage,

and that the tail-rod and the mirror are approximately truly in line with the optic axis of the microscope. This is important. A slight tilting of the mirror will then be sufficient to fill the tube with light. For an objective lower than $\frac{1}{2}$-inch or $\frac{2}{3}$-inch the condenser will not generally be required, and in this case the concave mirror and the flat side of the flame can be used. The concave mirror should be adjusted at such a distance from the object on the stage that the rays of light are approximately focussed on the latter. A little reflection will show that when parallel or divergent light falls on a concave mirror the light becomes *convergent*, and the focus depends mainly upon the curve of the mirror itself. If the condenser be retained for these low-power objectives, the upper lens should be removed, or the field of illumination becomes inconveniently circumscribed; but for the reasons just given *the plane mirror must always be used with the condenser.* We have not infrequently seen workers, otherwise experienced, using the concave mirror with the condenser because of the increase of light obtained by the use of the concave mirror *without* the condenser, but forgetting that by so doing they are throwing upon the condenser convergent instead of parallel light, and making it impossible to satisfactorily focus the condenser itself.

Use of Condenser.—For objectives above $\frac{2}{3}$-inch the use of the condenser is advisable, and for higher powers imperative, if the full value of the objective is to be realized. In Continental microscopes, until recently, a sub-stage condenser was the exception rather than the rule. In many of our English laboratories its use, therefore, is even yet scarcely understood, because of the curious prejudice in favour of the Continental stand:

but though the Continental makers turn out excellent objectives, they have apparently only latterly begun to realize that an objective of high aperture has really no advantage over one of low aperture unless used with a suitable condenser.

Having so arranged lamp and mirror that the object is properly illuminated, it will be necessary then to focus the objective upon the slide, and, having done that, to adjust the condenser up or down, until the image of the edge of the lamp flame appears distinctly in the centre of the field. The light is thus correctly adjusted, its rays being brought to a focus upon the object, and so entering the objective undisturbed. To a beginner the partially illuminated field seems strange, but he must remember that in a critical image it is necessary to get the maximum perfection of definition in that portion of the object immediately under examination, and the rest may be ignored. If, however, a larger field be required, the flame, having been focussed, can then be turned broadside on, without altering its other positions. For ordinary work this is usual.

In earlier days it was customary, after focussing the light, to rack the condenser either up or down until the field was fully illuminated, and it is said that the Quekett Club, which has done so much for amateur microscopists, held two vehement rival schools, one of which maintained that the condenser should be racked up, and the other that it should be racked down. All these matters have now been settled by the realization of the real principle, and even more, perhaps, by the improvement in objectives, by which, under such illumination as now obtains, hidden structure has been brought to light that was before not even suspected. It may be well to warn beginners against racking the

condenser so high as to drive the slide up against a high-power objective.

The cone of light transmitted by the condenser should approximate to that of the objective, but few objectives will stand solid cones of light equal to their own apertures. If the worker is using the Abbe illuminator of 1·2 N.A., he will, of course, only obtain a total aperture of 0·1 N.A., unless the condenser is in immersion contact with the under side of the slide. Theoretically, therefore, this condenser is suitable for lenses of 0·1 N.A. and even more, and suitable also for lenses of lower apertures by the simple process of stopping the condenser aperture down by means of the iris or other diaphragm. The worker soon becomes expert in the use of the iris diaphragm, but beginners must be cautioned against the too prevalent tendency to cut off an unnecessary portion of the marginal rays in order to secure contrast in the image. By so doing the latter suffers rather than gains, diffraction images being set up. As a matter of fact, the diaphragm should be closed gently and cautiously, just enough to slightly accentuate the image and no more, and it will generally be found that, under these circumstances, if the eyepiece be removed, the back of the objective, examined down the empty tube, is found to be from two-thirds to three-quarters filled with light. A good objective should stand satisfactorily what is accordingly often spoken of as a three-quarter cone of illumination.

Oblique Illumination.—In most cases strictly axial, *i.e.*, central, illumination is used, but there are certain cases—such, for instance, as the structure of diatoms—for which oblique illumination is necessary. Formerly this was obtained by swinging the mirror, or mirror and condenser combined, slightly to one side, but more

generally now by the insertion of a stop in the carrier beneath the condenser. In this stop a narrow slot has been cut, or a segment cut out. The effect of this is to throw an oblique beam of light in one direction across or down the diatom, according to arrangement, and thus to bring into greater prominence shadows of the fine striæ, otherwise almost invisible owing to their exceeding minuteness. To do this properly requires considerable practice and experience, as may be readily understood when we remember that the 'markings' in *Amphipleura pellucida* exceed 90,000 to the inch.

Centring Condenser.—The necessity of making sure beforehand that the mirror and tail-rod are truly in line with the optic axis of the microscope has been already alluded to (p. 128). If this be not the case the image of the lamp flame will appear to shift in position as the tube of the microscope is racked up and down. It is necessary, in addition, that the condenser itself shall be truly centred with the objective. Microscopes fitted with a simple sub-stage ring are only approximately centred, but the mounting of the condenser is generally slightly elliptical, and by rotating the condenser an approximately central position can generally be obtained. The value of a proper centring sub-stage is now evident, and the simplest way of centring the condenser is to make a minute ink-spot in the centre of the top lens, and centre accordingly, afterwards wiping the ink-spot off. Some condensers were formerly fitted with a small brass perforated cap for this purpose. The more usual method is to focus the image of the iris diaphragm when practically closed, and to centre accordingly.

The image of the iris diaphragm will only be seen when the objective is racked some distance upwards, and this is preferable to racking the condenser down,

as the latter seldom remains in the same alignment with the objective under these conditions. With high powers it is not often possible to get an image of the diaphragm small enough to centre by, and therefore the initial step is taken with a $\frac{3}{4}$-inch or less. The condenser being centred, it and the objective are focussed on the object on the stage, and the image of the flame brought to the centre of the field either by adjusting the mirror slightly or by a small movement of the lamp. With a change of objective and consequent alteration of centring it is only necessary to bring the lamp flame back into the centre of the field by adjusting the centring screws of the condenser, the mirror and lamp remaining untouched.

It may be advisable here to mention that almost all objectives differ in the centring of their mounts, and therefore with high-power work the centring of the condenser will vary for each objective. A rotating nosepiece, as stated on p. 12, also disturbs the centring of the objectives, and consequently of the condenser, as no nosepiece is constructed with sufficient accuracy to insure absolute truth in this respect.

Focussing Condenser.—The principle which underlies the use of the condenser amounts really to this—that the light and image rays must coincide. If the condenser be adjusted so that its focus be *beyond* or *below* the object on the stage, the rays of light will not coincide with the focus of the objective, but will cross, and the result will be an imperfect image.

There is one other point that may be mentioned in connection with the focussing of the condenser. So far it has been purposely assumed that the source of light has been that of a lamp, which gives slightly divergent light. In Dr. Carpenter's book on the

microscope it is rightly pointed out that ordinary daylight, owing to its diffusion, does not give parallel light, though a window acts to some extent as a limiting diaphragm. The focus of the condenser differs somewhat, therefore, for lamplight and for daylight.

Dark-Ground Illumination.—The use of oblique illumination by means of suitable spots placed beneath the condenser in a carrier adapted for that purpose has been already alluded to. There is also the form of illumination generally spoken of as 'dark-ground illumination.' In this case a small central spot, supported on arms, occupies a similar position, and by cutting off those central rays of light which would otherwise enter the objective gives an absolutely dark field in the microscope. When a suitable object is interposed on the stage, however, the annular rays of light that would otherwise escape the objective are intercepted by the object, and thus diffracted into view. The result is often singularly beautiful — diatoms, foraminifera, and transparent zoophytes being exhibited shining upon an otherwise dark and contrasting background. To obtain the best results it is necessary to bear in mind that the diameter of the stop must be proportioned to the aperture of the objective. Thus, a low-powered, and presumably low-apertured, lens will require a small stop, whilst a high-powered and high-apertured lens will require a much larger stop. It would not be of much advantage if we were to give methods for ascertaining the size of stop required; if necessary, an experimental stop can readily be constructed out of blackened cardboard. The condenser will also require a certain amount of adjustment, and a Davis shutter, which is a small iris diaphragm fitted *above* the objective, by its facility for reducing the aperture of the objective, enables one to

obtain perfect background illumination. With the older condensers dark-ground illumination is, however, only possible with objectives of moderate power and aperture, say, not exceeding 0·6 N.A. The value of this means of illumination for really critical work need not be discussed here.

Before leaving the subject of oblique illumination, it may be mentioned that the mere slight tilting of the mirror will often greatly increase the resolution of difficult objects.

Reflected Light.—Opaque objects are illuminated by several methods. The most frequent way is to focus the light directly upon the object by means of a bull's-eye stand condenser, remembering that the flat of the condenser must be nearest to the object and quite close to it, the focus being short. If a lamp be used it will be necessary to raise it well above the stage. A better way is by the use of a 'side silver reflector,' which is a small silver parabolic mirror placed close to the object, and reflecting the rays of light thereon from a lamp placed quite near and about level with the stage. Its management is soon learnt. The lamp rays may be reinforced by means of parallel light from a bull's-eye condenser, as explained below. Perhaps the most perfect means of illuminating opaque objects is by the now but little used 'Lieberkühn.' This is really a speculum fitted above and round the objective, the light being thrown from *beneath* the object, and reflected down again upon it. Its disadvantages, and those which have caused it to be largely disused, are that each objective must be fitted with its own Lieberkühn, and that the object must be mounted, not upon a black background, but in such a way as to allow the light to pass up and around it. When dealing with mounting it will be

pointed out that the generally recommended method of mounting opaque objects upon a black background is not only unnecessary, but inconvenient. The writer invariably mounts such objects in an ordinary cell, and puts under them a plain slide upon which a disc of black paper has been fastened. What more is needed ?

Use of Bull's-eye Condenser.—Before leaving the subject of illumination, the bull's-eye condenser must be considered. The great spherical and chromatic aberrations of this lens were alluded to in Chapter V., p. 88, and these render it unsuitable for really critical work on account of its bad definition. For this reason its general use cannot be advocated, save for opaque illumination. Should it be necessary, however, to fill the field with light by its means, its optical properties must be borne in mind, and it must be remembered that to obtain parallel light the condenser must be placed close to the flame of the lamp, and with its flat side against the flame. The bull's-eye must, of course, also be placed both centrally and at right angles with the direction of the light. It is an assistance to beginners if they do their focussing, both with bull's-eye and even with condenser, upon a sheet of note-paper placed in the requisite position. If the bull's-eye be used, it must be properly and carefully adjusted, or it will only interfere with the proper focussing of the condenser.

Focussing Objective.—To pass now to the focussing of the objective itself. This needs but little explanation, but it may again be advisable to point out (see p. 114) that the so-called focal length of the objective does not in any way represent its distance from the cover-glass of the object. In fact, with increase of aperture the objectives have got closer and closer to the object. When using high powers it is a help, and sometimes a

preventive of damage, if the aperture of the stage, as is customary in English stands, is made sufficiently large to admit of the insertion of the finger underneath the slide, so as to slightly lift or tilt its fore-edge. A high power can then be safely brought down upon the object, and, the approximate distance being found, the finger can be removed, and the objective brought gently to its ultimate focus.

The use of the correction collar or adjustment of tube-length for differences in the thickness of cover-glass has been fully dealt with in Chapter VI., pp. 109 and 124, but it really requires a trained and critical eye, as well as a critical object, to enable these adjustments to be satisfactorily made. The beginner is recommended to find out at the time of purchasing whether his objectives are corrected for the $6\frac{1}{2}$-inch or 10-inch tube, and to remember that they perform properly only on the tube for which they are designed. Most students' objectives, as already stated, are corrected for the short tube.

Care of Eyes.—There are a few more suggestions that may be useful to the beginner. The first is to remember never to use a stronger light than is necessary. Nothing is more fatiguing to the eyes, or more likely to work mischief, than excessive glare; but if reasonable precautions be taken the use of the microscope does not seem to be injurious to the eyesight. Some people are much troubled with what are called 'floating flies' in the eye, but this is to a certain extent a question of ease of position. The second rule is to accustom one's self to keep *both* eyes open. The screwing up of the eye not in use is a most injurious and unnecessary habit. At first, doubtless, some difficulty will be found, and the eye that is not looking down the tube will be distracted by external influences, but this difficulty is only tem-

porary, and a little perseverance will overcome it. Some writers recommend a shade, but the writer has advised many beginners to commence simply by holding the hand a short distance from the eye, and to gradually move it further away as they gained experience, until finally it was no longer necessary at all. All workers have a tendency to use one eye more than another, and in this case the eye most used becomes generally rather less sensitive to brightness of image, but more capable of perceiving critical points. But every worker should learn to use either eye with equal facility.

Coloured Screens.—Various tints of blue or yellow glasses, or a disc of ground glass, are useful for moderating the light, and in some cases for accentuating the image.

Remember to use no higher magnification than is absolutely necessary. The real microscopist uses the lowest power that will serve his purpose, for reasons that a very slight acquaintance with the microscope makes abundantly evident, and in all probability the most generally used lens is that of the modest inch.

Care of Fine Adjustment.—Remember also that the fine adjustment is a delicate piece of mechanism, and endeavour to save it (and the mechanical stage, if there be one) from the very first. Any one of the microscopes described will satisfactorily and easily focus a $\frac{1}{6}$-inch by means of the coarse adjustment alone. Do not bear heavily upon any of the adjustments; endeavour to balance them gently between the finger and thumb, that the motion may be uniform; and do not on any account roll the fine adjustment by pressing one finger to one side only of the milled head.

Care of Objectives.—Objectives should be carefully treated, and it should be borne in mind that they are

delicate pieces of apparatus. Dew on a lens should be allowed to evaporate, dust on the back lens should be removed with a soft camel-hair or sable brush, and if the lenses really require cleaning, a specially soft piece of chamois leather or cambric should be kept free from dust, and used for that purpose only. The lenses should never be unscrewed—that is a matter for a first-rate optician only, and the maker is the proper man. An oil-immersion lens should be carefully and gently wiped immediately after use, and if by any chance any of the oil should have dried on the lens, it is best to put another drop of oil on it, and to leave it for a time before wiping clean. Dr. Henri Van Heurck says there is nothing better than the ordinary saliva of the mouth for cleansing immersion lenses. If benzole or xylol is necessary, it should be applied to a piece of blotting-paper, and not allowed to soak into the mounting of the lens. Under any circumstances use as little pressure and friction in cleaning as possible. When objectives are in use, but temporarily removed from the microscope, they should be laid end upwards on the table to keep out the dust. For this reason it is well also to keep one of the eyepieces habitually in the tube of the microscope.

A glass shade is preferable to the ordinary wooden case, except, of course, for travelling, as the microscope is apt to get jarred or knocked about through being constantly taken out of and put into its case. It is well, however, to remember that a microscope should not be allowed to stand in direct sunlight, if for no other reason than that the heat might prove injurious to the balsam or cement connecting the lenses of the objectives.

Care of Oculars.—The eyepieces, like the objectives, should be kept clean and free from dust. The dust can be readily localized by reducing the light by means of

the iris diaphragm or otherwise, and then rotating the eyepiece. The objectives should not give much trouble in this way, and it will often be found that what was apparently dust on the back lens of the objective was actually dust on the cover-glass of the object or on the top lens of the condenser. This can be localized in like manner by moving the slide or rotating the condenser.

Use of Camera Lucida.—Some little practice in using any form of camera lucida, as described in Chapter V., p. 94, is always necessary. The real secret of success lies in arranging the illumination satisfactorily, and this is more easily arrived at, whether the camera be fitted with moderating glasses or not, by using two lamps, one for the microscope as usual, and one to illuminate the paper. A little adjustment of the light from each lamp is necessary until the pencil and drawing can be seen without losing the image in the microscope.

Beale's camera lucida is perhaps the most popular. A makeshift camera on this principle can be made by means of a piece of cork, a cover-glass, and a couple of pins, all that is necessary being to adjust the cover-glass in front of, but at an angle of 45 degrees with, the eye-lens of the eyepiece. The cover-glass gives, however, a somewhat troublesome double reflection, and this is obviated in Beale's arrangement, as supplied by the opticians, by the use of tinted glass. The Abbe form of camera lucida is considered by many workers to be the best in the market, but it is also the most costly. The paper must be parallel to the object, and if the microscope is therefore to be used in any but the vertical position, the drawing-board must be sloped accordingly.

In the newer form of combined eyepiece and camera lucida, made by Swift, Leitz, and other makers, some

little practice is required to get the pupil of the eye placed in such a position over the prism that neither the image of the object nor of the paper overpowers the other. The beginner will find that in all forms of cameræ lucidæ the secret of success, as we have already pointed out, lies in the proper adjustment of the illumination for both microscope and paper. It is here that the value of an independent lamp for the paper makes itself felt. With low powers the illumination in the microscope is the stronger, and the lamp flame must be adjusted accordingly, or a piece of white paper even may be placed over the mirror when that is used. With high powers the paper is generally the brighter, and tinted screens must be used or the light modified. The usual standard for distance between eyepiece and table is 10 inches, and this should be adhered to approximately. Any variation will alter the size of the drawing. It may not be superfluous to add that short-sighted people will require to use their spectacles if they are to see the paper and pencil clearly. The pencil should have a sharp point, and the lines should not be drawn too heavily in the first place. With all forms of drawing apparatus the paper must lie in the position for which the camera lucida is designed, as detailed above, or the result will be an elliptical image.

Use of Micrometer.—The use of the stage micrometer in connection with the camera lucida will suggest itself to anyone. It is only necessary to replace the object on the stage by the micrometer, taking care not to alter the other adjustments of the microscope, and to note the measurements thus shown upon the drawing. Supposing the portion of the drawing to be measured corresponded with $\frac{1}{100}$ inch as shown on the stage micrometer, and with 1 inch when measured with an

ordinary rule, the actual magnification on the drawing is 100 diameters. If the micrometer be a millimetre scale it will be necessary to provide one's self with a rule divided in millimetres, or to convert the English measurements accordingly, either by reference to a table or by calculation. For rough purposes the English inch may be taken as 25·4 millimetres (see scale in Appendix).

The use of the stage micrometer in conjunction with the eyepiece micrometer has been dealt with on p. 93. In making measurements by this method when using high powers difficulty is often encountered in causing the object on the stage or the stage micrometer to come into exact alignment with the lines in the eyepiece. To obviate this a mechanical stage is a great convenience, or the form of micrometer designed by Mr. Jackson, with a slight adjustment to the scale by means of a screw. The most perfect form of micrometer eyepiece is the screw micrometer, containing one fixed and one travelling wire, the movement of the latter being accurately recorded by means of a drum, whilst each revolution of the drum corresponds to one of many serrated teeth in the field of view.

Measuring.—When the student is making accurate micrometric measurements it should be remembered that the divisions on the stage micrometer are not uniform, and that the mean value should be accordingly taken. Further, the stage micrometer should be used in every set of measurements, the usually recommended plan of making a record with different objectives and eyepieces once for all, for comparison, being manifestly untrustworthy. Errors due to diffraction in the real edges of objects mainly affect high powers, and it may suffice here to simply mention their existence.

Test Objects.—In concluding these elementary hints on the actual management of the microscope, the beginner is strongly advised to obtain a few 'test slides,' and diligently to practise himself in their examination. For low powers there is nothing more suitable than the fine hairs on the tip of the proboscis of the blow-fly. These should come out quite sharp, black, and finely pointed. For medium powers the old-fashioned 'podura scale' (*Lepidocyrtis curvicollis*), mounted dry, may be recommended, and if the beginner can get the 'hairs' on these sharp and well marked, having the appearance of minute exclamation stops, and not running in the least into each other—we say nothing of interior 'marks'—he has learnt much in the management of his microscope, and in obtaining a 'critical image.' Unfortunately, the scales themselves vary very much, and it is not always easy to pick out a coarse enough scale that will be within the beginner's or even the objective's powers. In obtaining such a critical image the worker will bear in mind not only what has been already said on adjustment of the light by means of the condenser and otherwise, but also the warning against an excessive shutting down of the cone of illumination by means of the iris diaphragm. This latter, whilst apparently at first sight increasing the contrast, really breaks down the definition of the objective, and leads to woolliness of outline in each individual mark on the scale, or even to a ring of refracted light round each. For high powers, especially immersion lenses, a slide of bacteria is suitable—say a slide of *Bacillus tuberculosis*, showing the characteristic beaded appearance. The diatom *Pleurosigma angulatum* is also a useful test object. To test for colour a thin section of deal may be used, or preferably a hair of *Polyxenus lagurus* or the diatom *Pleuro-*

sigma formosum. For flatness of field a stage micrometer is better than an Echinus spine. These are mentioned as helpful aids in mastering the use of the microscope only. The proper testing of objectives requires long practice, skill, and experience.

Adjustments.—If the microscope requires adjustment, these adjustments should be made with the utmost care. Most microscopes by our best English makers have the wearing parts 'sprung,' so that the adjustments may be readily effected, but even then a little attention to the tools with which the work is done may be recommended. The screw-driver, for instance, should be in good condition.

It is well also to bear in mind that the lacquer on the brasswork of the microscope, placed there not so much for appearance as for the prevention of oxidation, is destroyed by alcohol.

Finally, our advice to the beginner who may wish to oblige a friend by lending him his microscope is—don't.

CHAPTER VIII

MOUNTING FOR THE MICROSCOPE

It now only remains to add a few hints on mounting, and these will be made as simple and practical as possible. The beginner must bear in mind that mounting for the microscope has become quite an art, if not a science, and the list of reagents, stains, and media used for special purposes would be quite a formidable one. Fortunately, the requirements of beginners and amateurs, especially those for whom this book is written, are much more easily dealt with, and we shall confine ourselves to the simplest and most commonly used methods, trusting that as knowledge grows and experience comes with it the beginner will learn more of such advanced methods from works dealing with the subject.

It is, of course, only with very low powers, and when the nature of the investigation admits of it, that an absolutely unprepared and unarranged object can be examined. For this purpose a pocket lens is infinitely preferable to the compound microscope, with all its complications and refinements. For examination with the latter instrument even opaque objects require to be properly displayed, whilst objects to be examined with transmitted or direct light—that is, by means of light that passes through the object—require very careful preparation beforehand.

Slips and Cover-Glasses.—Wooden slips and paper-covered slips are now very rarely used, 3-inch by 1-inch glass slips being almost universal. These can be obtained from any optician. They should, preferably, have ground edges, and for general purposes should be of medium thickness. They will cost from twopence to fivepence per dozen, according to quality, or less for a larger quantity. If any of them should be found to have scratches or specks in the centre they should be put aside for making opaque mounts. For exceptionally large mounts slips 3 inches by $1\frac{1}{2}$ inches can be obtained. The cover-glasses should be circular, in thickness from 0·006 inch to 0·008 inch, and might vary in size from $\frac{5}{8}$ inch to $\frac{7}{8}$ inch diameter. It would be well to provide one's self with a stock of $\frac{5}{8}$-inch, $\frac{3}{4}$-inch, and $\frac{7}{8}$-inch cover-glasses, and to note their thickness at the time of purchase, and, generally speaking, to adhere afterwards to the same standard for ordinary work. High-power work with objectives of very short focus may require thinner cover-glasses to be used. The purchase of a dozen or so slips with excavated cells of various sizes—*i.e.*, with concavities ground in their centres—is also recommended.

Before use, all slips and covers must be scrupulously cleaned. It is generally sufficient to wash them with hot water and soap or soda, but for special work more drastic measures may be necessary. The writer generally uses a fairly strong and hot solution of Hudson's soap, with subsequent careful rinsing and polishing with an old cambric handkerchief. The great thing to be avoided is any suspicion of grease, even from the fingers themselves. Cover-glasses must be finally polished with chamois leather, and as they are very thin and, of course easily broken, various contrivances, such as buff blocks,

are obtainable for the purpose. With a little practice, however, it is quite easy to hold half the cover-glass in a piece of chamois leather between the finger and thumb, but not edgeways, and to polish the other half, turning the glass round meanwhile.

Mounting Opaque Objects.—The mounting of opaque objects and of objects that can be mounted dry will be first dealt with, this process being comparatively simple. The various apparatus, reagents, media, stains, etc.,

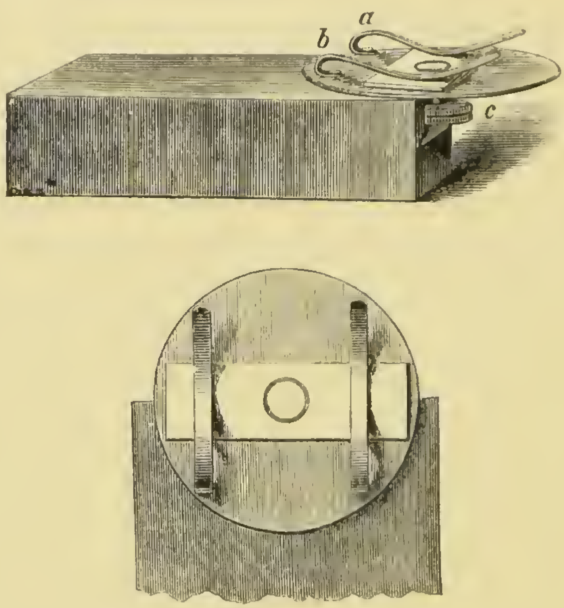

FIG. 74.—TURN-TABLE.

will be mentioned as we proceed, and their uses will then become apparent at the same time. Accordingly, we shall here require a **turn-table.** This is a circular brass plate about $3\frac{1}{2}$ inches in diameter, mounted so as to rotate upon a centre, the upper surface of this plate having concentric rings engraved upon its surface. These latter serve as a guide in centring the slide upon the rotating plate. There is also a pair of clips to hold

the slide in place. The turn-table is mounted on a wooden block or iron stand, which serves as a support for the hand. The 'self-centring' turn-tables are not recommended. We shall also need two or more good sable brushes, which are best and cheapest in the long-run. These should be about $\frac{1}{16}$ inch and $\frac{3}{32}$ inch in diameter. Also a pair of steel or brass forceps, not too narrow, a bottle of gold-size, a bottle of Brunswick black, and a bottle of gum arabic. All of these are obtainable from any optician.

The usual plan with opaque objects is to place a slide on the turn-table, centre by means of the concentric rings, and then run a disc of Brunswick black of the requisite size in the centre, rotating the stage meanwhile by means of the forefinger of the left hand and the milled head beneath. As soon as this black disc is dry, a piece of black paper of the same size is cut out and gummed upon it. The black paper should not have a glazed surface. Then upon the disc is built up a cell of the requisite depth to contain the object. As has been said before, however, (p. 134), this method of mounting opaque objects upon a black background is not only unnecessary, but often inconvenient, as it renders the use of transmitted light impossible, if it should be wanted; neither can such slides be examined by means of a Lieberkühn. It is best, therefore, to omit the black background, and instead a similar disc, or two or three discs of various sizes, can be put upon thin slips, and one of these can then be placed beneath the slide carrying the object when it is being examined by reflected light.

Cell-Making.—The cells are made by running a ring of gold-size of the same diameter as the cover-glass that will be used. This is done by means of the turn-table, and is not difficult. It is not advisable to use too full a

brush, and the gold-size should be of the right consistency—neither too thick to leave the brush, nor so thin as to run away from position. The tip of the brush is used, and the table rotated not too quickly. For very thin objects one ring will suffice, but thicker objects will need two or three rings, added one on the top of another, each ring being added, however, only when the other is dry. If a few such rings do not give sufficient depth it is advisable to build up the cell by other means. Rings may be cut out of stout paper, or thin and good cardboard, then steeped in paraffin and dried. Stout rings of ebonite, glass, tin, etc., can be obtained from the optician's. It is only necessary to attach these to the slide by means of a ring of gold-size, pressing down the ring firmly, and even giving a very slight twisting motion to make sure of there being no air-bubbles to prevent perfect contact. If the cells of gold-size when dry should not be quite level, they can easily be rubbed down on a piece of very fine emery laid on a flat surface. The object itself must be fastened in place by means of a drop of gum placed upon the slide. Care should be taken that this drop of gum is hidden by the object, unless that is impossible. Thin objects, such as wings, petals, leaves, etc., may generally be kept in place merely by the pressure of the cover-glass. Very minute objects, such as pollen grains, for instance, are made to adhere by means of a thin film of very weak gum, which is placed on the slide and allowed to dry. Breathing upon the slide will then moisten the film of gum sufficiently to cause the pollen to adhere when placed thereon. In every case, however, it is of the utmost importance that the gum and gold-size should be allowed to dry thoroughly before the cover-glass is put on, or the remaining moisture will settle on

the under side of the cover-glass and utterly spoil the slide. A final ring of gold-size is then run on, and this last should be allowed to dry until it is just sticky only, when the cover-glass may be gently lowered into place by means of a pair of forceps, and the edges pressed gently down, care being taken that the cover-glass adheres all round its edges. Finally, the slide is finished by a coat of Brunswick black over all, just covering the edge of the cover-glass.

Cements.—Instead of gold-size, other cements may be used, but gold-size, especially if old, will be found most satisfactory, save for certain fluid mounts. Bell's cement is excellent, and so is Ward's brown cement, whilst Mr. Cole recommends a special shellac black enamel. Marine glue is always an abomination, and many workers have long discontinued its use. Under any circumstance it must be applied hot.

Mounting in Canada Balsam.—The mounting of opaque or dry objects has been dealt with at considerable length because it is the easiest, and forms a natural introduction to mounting in preservative media. There are many more or less specialized methods of the latter, but it will be sufficient if we confine ourselves to two—namely, Canada balsam and glycerine jelly. These two methods, and especially the first, are used universally. Objects or sections may need careful preparation beforehand, but we will deal with these methods afterwards, assuming here that, as frequently happens, no such preparation is necessary. Canada balsam is best purchased ready for use, in which case it will be obtained as a solution in benzole or xylol. It should be kept in a wide-mouthed bottle, provided with a glass rod for dropping the contents upon the slide, and with a closely-fitting cap instead of stopper. The bottle must be

kept closed as much as possible. Glycerine jelly is practically a mixture of glycerine and gelatine, which liquefies when warmed. It can be obtained in shilling bottles fitted with an ordinary cork. The first important distinction to be noticed between them is that, whilst objects mounted in Canada balsam must be freed from every trace of water, those mounted in glycerine jelly must be first soaked in water or some aqueous medium.

In both cases a **mounting-table** (Fig. 75) and **lamp** should be provided. The table in its simplest form is a plate of brass about 4 by 3 inches, standing on four legs about 3 or 4 inches high. The lamp is a small glass

FIG. 75.—MOUNTING-TABLE.

methylated spirit lamp, with a glass top, such as is used in laboratories, to go beneath the table.

The actual process of mounting in Canada balsam may be carried out as follows: We will assume that the object has received a final soaking in turpentine. Having carefully cleaned both slip and cover-glass, the latter is taken up in a pair of forceps, and, the slide having been breathed upon to slightly moisten it, the cover-glass is placed on the slide, and pressed there to make it stay in position. The slide is then placed on the table, and the lamp lighted and put beneath. In less than half a

minute the plate will be sufficiently warm—the heat should be no greater than will allow of the finger being placed on the end of the slide. A drop or two of balsam is then placed on the cover-glass which is on the slide, care being taken that it does not overrun the margin of the former. Into this the object is then lowered or slid by means of a section-lifter (a cover-glass held in a pair of forceps may serve) and a needle set in a handle. Care should be taken to get the object right down under the balsam and close to the cover-glass. The object should then be examined with a pocket lens to make sure that its position is satisfactory, and to see that no air-bubbles are visible in or around it. It is then placed under a watchglass or other cover to protect it from dust, and put aside for twelve hours to harden. It will be found that the balsam skins over very rapidly on exposure to the air, and no time, therefore, must be lost. The warming of the slide partly obviates this. After hardening for twelve hours, it is as well to make an examination under the lowest power of the microscope before proceeding further, to make sure that the object itself is properly in position and free from air-bubbles or contained air. The slide is then again placed on the mounting-table, and the insertion of a needle will readily release the cover-glass. Warm as before, apply a fresh drop to the centre of the hardened balsam. lift with a pair of forceps, reverse quickly, and lower gently down upon the slide, pressing down carefully so as to squeeze out the excess of balsam and to carry any air-bubbles with it. The cover should now lie flat on the slide. It is better to have a slight excess of balsam rather than a deficiency. In case of the latter a drop must be put against the cover-glass, when it will quickly run in by capillary attraction. Small bubbles, other than any

embedded in the object itself, may be neglected, one of the advantages of Canada balsam being the readiness with which it will absorb these. There are certain objects, however, which are most difficult to free from larger bubbles than the balsam can absorb. In such cases it is often practicable to again heat the mounting-table, whilst holding the cover steadily, but not too heavily, in position by pressing on its centre with the handle of a dissecting-needle until the balsam is seen to boil. At once remove the lamp, but hold the cover-glass steady until the balsam seems to have set again. By this means, though it needs great caution, the bubbles will be driven clear of the cover-glass by the ebullition of the balsam. Wire spring clips can be obtained for a penny each, and it is advisable to slip one of these on before putting the slide on one side to harden. This may take twenty-four hours, or it may take a week, according to the amount of balsam used or exuded, and to its consistency. Under any circumstances it is well not to hurry matters. The excess can then be removed with a sharp knife nearly up to the cover-glass, and the remainder cleaned up nicely with a rag dipped in turpentine, methylated spirit, or benzole.

The advantage of the method of mounting in Canada balsam just dealt with is not only its comparative facility, but that it results in getting the object close to the cover, a point that may be of importance with high powers. It also insures the object remaining in position, very minute objects having an irritating tendency otherwise to be carried up to or beyond the margin of the cover-glass as soon as it is lowered upon the slide. At the same time, in many cases it is quite safe to mount the object directly on the slide. In fact, it must be admitted that this is the most usual method, and the

mounting-table also is generally too little used. The process is the same, except that it is generally carried through in one operation. A drop or two of balsam is placed on the slide, the object worked into it as before, if necessary another drop of balsam added, and then the cover-glass gently lowered and pressed down. If the cover-glass is lowered with one edge first it carries air-bubbles away more readily, but it also has a tendency to displace the object. The beginner will find that at first he uses either too much or too little balsam, but he will soon learn to judge this. Excavated cells, which are used for thick objects, but not for those thick enough to require an actual cell, are rather troublesome at first, as, unless there is balsam sufficient to completely fill the cell, an air-bubble will be found under the cover-glass, and it is not always easy to get rid of this without displacing everything.

Mounting in Glycerine Jelly.—Mounting in glycerine jelly is simpler than mounting in Canada balsam, and the preparation beforehand is also simpler. The object must be well soaked in water, and every trace of alcohol, turpentine, etc., got rid of. Owing to the fact that glycerine jelly does not absorb air-bubbles like Canada balsam, it is well to soak in water that has been recently boiled for about ten minutes and allowed to cool. This steeping is preferably done in a stoppered bottle or jar. Prolonged soaking in water is a great aid in getting rid of air-bubbles embedded or entangled in the object, and will generally prove effectual without the aid of an air-pump. It is advisable to soak finally in a mixture of glycerine and water—say one-third of the former—before mounting. The process of mounting is carried out as follows : The slide is placed on the brass table, the object is transferred to its centre by means of the

section-lifter, and any excess of water removed by the edge of a bit of blotting-paper, care being taken that the latter does not come in contact with the object itself. By means of the point of a knife, a small spatula, or other similar instrument, a small portion of glycerine jelly is then placed on the object, the requisite quantity being easily estimated, the lamp lighted, and placed beneath the brass table. In about a minute the glycerine jelly will begin to melt, and the lamp is promptly removed. Any air-bubbles should be skimmed off before the cover-glass is put on, and as the glycerine jelly will only solidify again by cooling, there is no need to hurry the process. After an examination the cover-glass may be lowered carefully into its place, a clip slipped on, and the whole slide put aside for half a dozen hours or more to set. The excess of jelly around the cover-glass may then be removed by means of a pen-knife, and the whole slide cleaned by dipping in a saucer of water or holding under a running tap, finally polishing with a bit of rag. Glycerine jelly is often used when mounting in built-up cells, but before doing this it is advisable to run a wetted camel-hair brush round the cell to make sure that no air-bubbles will cling to the sides or bottom. Pure glycerine is not often used for other than temporary mounts, as it will not set, but a mixture of glycerine and gum arabic, with a little arsenious acid, known as Farrant's solution, is often used, especially in histological preparations, as it dries at the edges. It is best bought, as home-made preparations are not always satisfactory.

Ringing Slides.—Canada balsam slides do not necessarily need ringing, though the writer's own practice is to ring all his slides, but glycerine slides should be finished off with a couple of rings of gold-size. The

process is very similar to that of cell-making. The slide is centred upon the turn-table, taking care to centre by means of the cover-glass and not by the slide, and a ring of gold-size run round the edge of the cover-glass. Care must be taken to just cover the edge of the latter, and not to overlap the slide too widely. Beginners generally take up too much gold-size in the brush. A neat ring is made by attention to this point, by turning the table at a moderate speed, and by raising the brush slightly towards the finish. Old gold-size is best, provided it will run easily. The second ring should be added after the first is thoroughly dry. Finally, a ring or two of Brunswick black or white zinc cement may be run over all as a neat finish. We have seen suggestions for various coloured cements to be used for various classes of objects—botanical, zoological, mineral, etc.—but if a distinction is to be made we think it should refer rather to the mounting medium employed. The writer's own practice, for instance, is to ring all opaque and dry mounts with Brunswick black, Canada balsam mounts with white zinc cement, glycerine mounts with white zinc cement with a fine black ring in the centre, and other mounts with a white ring on a black one. For use with immersion lenses *all* mounts must be carefully ringed with shellac cement or Hollis's liquid glue, or the cedar oil will dissolve the cement.

Glycerine.—In using glycerine mounting media it is well to remember, as pointed out by Dr. Carpenter, that they largely increase the transparency of organic substances, and though this is often advantageous, it may also sometimes result in so great a diminution of their reflecting capacity as to make them indifferent mounts. Glycerine acts as a solvent for carbonate of lime, and should, therefore, not be used for objects of a

calcareous nature. Such instructions in elementary mounting have been given as will enable a beginner to make rapid progress in the art if he is gifted with only a small amount of perseverance and patience, but it must not be forgotten that the actual mounting is but a part of the work required. Numerous subjects will need very careful preparation beforehand, and on the methods adopted and the skill and judgment with which they are carried out will depend much of the result. Many objects will need dissecting.

Dissection.—Most dissections, and especially delicate dissections, are done under water, with, perhaps, a little methylated spirit added if the object has previously been soaking for some time in methylated spirit or alcohol. In some cases it will be necessary to fasten the object down, and this may be done with pins on a weighted piece of cork placed inside the dissecting dish, or by running paraffin or some such compound into the bottom. Watchglasses with flat bottoms make useful dissecting dishes. Two or three needles set in light wooden handles will be required. with both straight and bent points, and these can readily be manufactured at home, or purchased for a few pence. In buying dissecting knives, those with ivory handles should be chosen ; they only cost 1s. 9d. each, as against 1s. 6d. for the ebony-handled ones, while the latter are so brittle as to break with very little pressure. There are a good many shapes of blades sold, but perhaps the most generally useful are the usual scalpel forms, the spear, and the spatulate-shaped ones. Forceps may be either steel, brass, or nickel, but perhaps the steel ones are best, and they should, of course, be carefully kept clear of rust. A few camel-hair brushes are also necessary, and a pair of fine scissors. Insects generally

require soaking in a 10 per cent. solution of sodium or potassium hydrate (caustic potash) for periods varying from an hour or two up to a week. Too much soaking will destroy the object, and also render it too transparent after mounting, whilst too little may leave it hard and difficult to deal with. A little thought and attention will therefore be necessary, and slight pressure with a blunt needle will tell whether the object is sufficiently soaked. In the case of large insects, like cockroaches, they should be soaked for several days until they begin to give off an unpleasant smell. The alkali must then be removed by soaking in several changes of clean water. The inside of the insect can be got rid of by gentle treatment with the camel-hair brushes. Plant subjects are best softened by long soaking in water.

Objects to be mounted in glycerine jelly or any similar medium can be transferred directly from water, but those to be mounted in Canada balsam must be first thoroughly dehydrated, and this is done by transference to one or two baths of methylated spirit, alcohol having a strong tendency to absorb water. In some cases—as, for instance, with insects that require arranging—the object should be arranged between two slides, tied together with two slips of visiting, or thicker, cardboard between the ends, and the whole immersed bodily for some hours in the methylated spirit. The spirit has a tendency to harden the structure, so it is necessary to do the arranging in this way beforehand. The object may then be 'cleared' from alcohol by transference to clove oil, xylol, cedar oil, or turpentine, but in many cases the clove oil, etc., may be omitted, and the object simply transferred from the methylated spirit to turpentine. From the turpentine the mounting in Canada balsam may be proceeded with,

as already explained in detail. It is necessary to again lay stress upon the fact that, whilst the turpentine stage always immediately precedes mounting in Canada balsam, and the object must be freed from every trace of water, the reverse is the case when mounting in glycerine jelly or similar media, as the object must then receive its final soak in water, and be free from every trace of turpentine, etc. Delicate sections generally need careful dehydration in graduated alcohols—30 per cent., 50 per cent., 75 per cent., and 95 per cent.

Staining.—The great value of staining is not to make 'pretty' objects for the microscopic cabinet—beautiful as the effects often are—but to differentiate the structure. This has now become a high art, and new methods for special purposes are being constantly introduced, especially in histology. With these the beginner, unless he is doing special work, such as human, animal, or plant histology, has nothing to do. though the time may come, when he is no longer a beginner, when he can refer to larger or special works dealing with the subject, around which so voluminous a literature has already grown. Of all stains, **hæmatoxylin** (the active principle of logwood) is the most generally useful, especially for vegetable sections. It is best purchased from the optician in an alcoholic or watery solution, and improves greatly with keeping. Before staining, many objects, such as vegetable sections, may require bleaching. Steeping in alcohol will generally have this effect, but a solution of chlorinated soda is an excellent bleaching agent without being too powerful. It is made as follows: 1 ounce of dry bleaching-powder is dissolved in a ½-pint tumbler of water, 2 ounces of washing soda are dissolved in another tumbler of water, after which the two solutions are mixed together,

well shaken, and allowed to settle for twenty-four hours or so. The clear fluid is then carefully decanted, filtered, and preserved in a stoppered bottle away from the light. Sections or objects to be bleached are first soaked in water, and then transferred to a small quantity of the chlorinated soda for a period of time varying from one to a dozen hours or more. They must afterwards be very thoroughly soaked or washed in several changes of clean water until every trace of soda is removed.

The process of staining is as follows: 10 to 30 drops of the stain, according to the requirements of the section or object, are added to 1 ounce of distilled water or alcohol, as the case may be, and the section is removed from water or alcohol to this stain, where it is allowed to stand from ten minutes to half an hour, or even longer. After washing in distilled water, it is generally recommended that the section be washed in ordinary *hard* tap-water, with a view to deepening the stain. Opinions differ as to whether this is necessary, but if it is done, and if the tap-water should not be sufficiently hard, about 10 grains of bicarbonate of soda added to 1 pint of distilled water will serve the same purpose. The section must then be promptly dehydrated by ten minutes' or more soaking in methylated spirit, cleared in clove oil until it sinks to the bottom, transferred to turpentine and mounted in Canada balsam. Sections in alcohol must, of course, be stained in alcoholic solutions, and all water avoided, unless they have first been passed through alcohols of decreasing strengths.

Overstaining with hæmatoxylin may be remedied by soaking a few minutes in a ½ per cent. solution of glacial acetic acid in distilled water, or in a solution made up of 1 part of 1 per cent. hydrochloric acid in distilled

water to 2 parts of absolute alcohol. This also rectifies overstaining with carmine.

Double Staining.—**Eosin** is likewise a useful stain, and may also be used for double staining together with hæmatoxylin. For double staining the section should be stained with hæmatoxylin as above, then transferred to dilute acetic acid in distilled water. After carefully washing away the acid, first with distilled and then with tap water, stain for five minutes or more in a 1 per cent. solution of eosin in alcohol, wash well in methylated spirit, clear in clove oil, and mount in Canada balsam.

Carmine and Aniline Stains.—**Borax carmine** and **acid aniline green** are useful for double staining vegetable sections. Mr. Cole's method is frequently used and quoted, and is as follows : The green stain is made up of 2 grains of acid aniline green dissolved in a mixture of 1 ounce of glycerine and 3 ounces of distilled water. The carmine stain is made by dissolving 10 grains of borax in 1 ounce of distilled water, and adding ½ ounce of glycerine and ½ ounce of absolute alcohol. Another solution is made of 10 grains of carmine dissolved in 20 minims of ammonia and 30 minims of distilled water. The two solutions are then mixed together and filtered. The process of staining is to place the section in the green stain for five to ten minutes, wash in water, place in the carmine solution for ten to fifteen minutes, wash well in methylated spirit, dehydrate and clear in clove oil, wash in turpentine, and mount in Canada balsam.

Section-Cutting.—The higher branches of **Section-cutting** will be beyond the necessities of the beginner, but plant sections of the simpler sort will be well within his powers. Very fair sections can be cut with a razor by holding the specimen between the finger and thumb.

A piece of pith forms a useful support. The finger is held horizontally so as to form a rest for the razor, the cut is made towards the operator, and the razor is drawn *through* the object with a diagonal drawing cut.

Hand Microtome.—A very simple little **Hand Microtome** can be bought, however, for 5s. and upwards (Fig. 76). It contains a tube in which the object to be cut is wedged between two pieces of cork, pith, or carrot, or by embedding in paraffin. At the bottom of the tube is a fine screw which raises the object as required after each cut, and at the top of the tube is a circular flange of brass or glass to serve as a guide for the razor.

The **Cathcart Microtome** (Fig. 77) is, perhaps, the

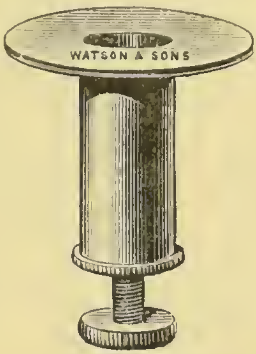

FIG. 76.—HAND MICROTOME.

most popular form, and is fitted with two parallel glass runners, whilst the tube is provided with a clamp. This is almost a necessity for paraffin embedding, as there is otherwise a tendency to slip in the tube. The cheaper form, arranged for embedding only, would cost 15s. The short lengths of tubes provided with the instrument as moulds for paraffin blocks are, however, inconvenient. A much better plan is to make little circular boxes of stout paper or thin cardboard, or, better still, to use a pair of brass L-shaped moulds which are

sold for the purpose. It is as well to buy the paraffin, which should have a melting-point of from 45° to 52° F., according to the temperature of the room in which it is to be used. If the paraffin is too soft the sections will wrinkle, owing to lack of cohesion, whilst if it is too hard they will roll up into tiny rolls. The best way to proceed is to cut a small slice of the specimen about $\frac{1}{4}$ inch thick, dry it, melt the paraffin over a water-bath, dip the section in the paraffin to give it a coat, hold it in the mould in

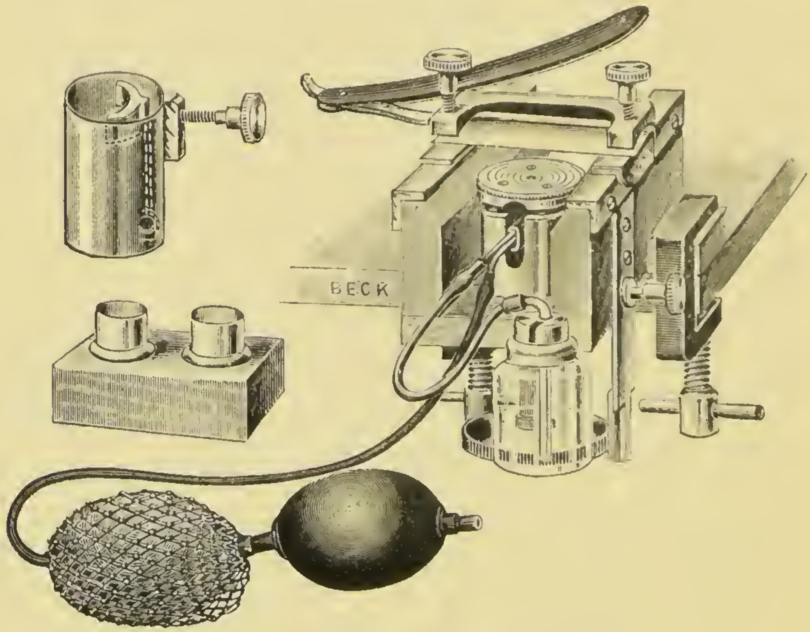

FIG. 77.—CATHCART MICROTOME.

the requisite position for the desired cut, run in the paraffin around and over it, and allow to cool. As the paraffin will shrink somewhat, especially at the top, the specimen should be well covered. When quite cool the block can be removed from the mould, and trimmed to the shape necessary to go into the microtome tube. With microtomes not fitted with a clamp the tube itself must be used as the mould. The razor used for

cutting must be kept well sharpened, and constantly wet by being dipped into a saucer full of methylated spirit, the sections being floated off as they are cut. The paraffin is then removed by means of naphtha, benzole, or turpentine, the turpentine washed off with alcohol, and the section placed in absolute alcohol or water, as the case may be. If it requires staining, this may be done either on the cover-glass or the slide, the method having been already explained. The subsequent washing can be done with a small wash-bottle containing water or 75 per cent. alcohol as required. Dehydrate with methylated spirit or alcohol of increasing strength, clear with clove oil, and mount in Canada balsam. Many sections are preferably stained in bulk before embedding. More complicated processes, requiring special apparatus and knowledge, such as **infiltration** or **freezing,** are better left until skill and experience are gained in the simpler processes. For further detailed information with regard to mounting, the reader cannot do better than refer to Mr. Cole's very full instructions in Cross and Cole's "Modern Microscopy."

Cleaning Slides.—Spoilt slides, failures, etc., are best immersed in a strong hot solution of Hudson's soap, after which the slides and covers are well washed with warm water, rinsed with methylated spirit, and polished with an old handkerchief.

All slides should be carefully labelled, and kept in proper boxes. The boxes should contain trays, so that the slides may lie flat, and these can be obtained very cheaply.

Conclusion.—In conclusion, may we earnestly urge upon those readers who do not use the microscope for any definite purpose the necessity of taking up some particular subject of study, and of using the microscope

as a means to that end, rather than as an interesting optical toy for idly examining heterogeneous slides, which by themselves will soon lose their novelty and interest ? Rightly used, the microscope is a means to an end, rather than an end in itself, and is capable of opening out to its owner ever-widening fields of fascinating and absorbing study and occupation. We cannot all be great scientific discoverers, but we may all be builders of the temple of science, if it be only to lay one single brick in that rapidly-growing structure, or to supply a little of the clay or straw out of which such a brick may be constructed by others.

APPENDIX

It may be helpful if a brief list is given of the most useful books dealing with the microscope, and with the general animal and plant life for which the microscope is so essential a means of study, to which are also appended short explanatory notes. This list makes no claim to be in any sense a complete bibliography of the subject.

Technology.

Bagshaw, W.: Elementary Photo-Micrography. *Iliffe.* 1s.

Bausch, E.: Manipulation of the Microscope. Ill., post 8vo. *Bausch & Lomb Co.*, 1901. (For beginners.) \$1.

Beale, Dr. L. S.: How to Work with the Microscope. 600 illus., cr. 8vo. *Harrison*, 1886. (Rather out of date.) 21s.

Bousfield, Dr. E. C.: Guide to the Science of Photo-Micrography. Ill., cr. 8vo. *Churchill*, 1892. (A thoroughly practical book.) 6s.

Clark, C. H.: Practical Methods in Microscopy. 8vo. *Boston*, 1894. \$1.60.

Cross, M. I., and Cole, M. J.: Modern Microscopy. Ill., demy 8vo. *Baillière, Tindall & Cox*, 1903. (An excellent book. Deals with the use of the microscope and mounting.) 4s.

Davies, T.: Preparation and Mounting of Microscopic Objects. Ill., 12mo. *Gibbings*, 1896. (Fair.) 2s. 6d.

Davis, G. E.: Practical Microscopy. 310 illus. and coloured front., 8vo. *W. H. Allen*, 1889. (Useful to beginners.) 7s. 6d.

FREY, Prof. H.: Technology of the Microscope. (Trans.) Ill., cr. 8vo. *New York*, 1880. $6.

FRIEDLÄNDER, Prof. C.: Microscopical Technology. (Trans.) Ill., 16mo. *New York*, 1886. $1.

GAGE, S. H.: The Microscope. 200 illus., demy 8vo. *New York*, 1901. (An introduction to microscopic methods. The most recent American book.) $1.50.

JAMES, F. L.: Elementary Microscopical Technology. 8vo. *St. Louis*, 1887. (A manual for students.) $0.75.

LEE, A. B.: The Microtomist's Vade-mecum. Demy 8vo. *Churchill*, 1900. (Standard work on advanced histological methods.) 15s.

MALLEY, A. C.: Micro-Photography; Wet Collodion, Gelatino-Bromide Process. Crown 8vo. *H. K. Lewis*, 1885. 7s. 6d.

MARSH, Dr. S.: Microscopical Section-cutting. Ill., 12mo. *Churchill*, 1882. (Chiefly animal.) 3s. 6d.

MARTIN, J. H.: Manual of Microscopic Mounting. Ill., 8vo. *Churchill*, 1878. (Chiefly medical.) 7s. 6d.

MILLS: Photography Applied to Microscope. 12mo. *London*, 1891. 2s.

NÄGELI, Prof. C., and SCHWENDENER, Prof. S.: Microscope, in Theory and Practice. (Trans.) 210 illus., 8vo. *Sonnenschein*, 1888. (Chiefly theory.) 21s.

PENDLEBURY, C.: Lenses and Systems of Lenses. Cr. 8vo. *Bell*, 1886. (After Gauss.) 5s.

PHIN, J.: How to Use the Microscope. (For beginners.) $1.40.

Practical Hints on the Selection and Use of the Microscope. 8vo. *New York*, 1881.

PRINGLE, A.: Practical Photo-Micrography. Ill., sm. 4to. *Iliffe*. (Perhaps the most practical book on the subject.) 3s. 6d.

'QUEKETT CLUB MAN': Handbook of the Microscope. 38 illus., cr. 8vo. *Roper*, 1887. (Selection and management.) 2s. 6d.

SEILER, C.: Compendium of Microscopical Technology 12mo. *Philadelphia*, 1880. $1.

SPITTA, E. J.: Photo-Micrography. 6 plates and 63 illus. large 4to. *Scientific Press*, 1899. (Excellent plates.) 12s. 6d.

SQUIRE, P. W.: Methods and Formulæ used in the Preparation of Animal and Vegetable Tissues for Microscopical Examination. Post 8vo. *Churchill*, 1892. (Standard book.) 3s. 6d.

STOKES, Dr. A. C.: Microscopy for Beginners. Ill., cr. 8vo. *New York*, 1887. $1.50.

VAN HEURCK, Dr. H.: The Microscope: its Construction, Manipulation, and Technique. (Trans.) 4to. *Lockwood*, 1893. 18s.

WALMSLEY, W. H.: The A.B.C. of Photo-Micrography. *New York*, 1903. $1.25.

WHITE, T. C.: Elementary Microscopical Manipulation. Ill., fcp. 8vo. *Roper*, 1888. 2s. 6d.

ZIMMERMANN, A.: Botanical Microtechnique. Demy 8vo. *Constable*, 1896. 12s.

TECHNOLOGY AND APPLICATIONS.

CARPENTER, Dr. W. B.: The Microscope and its Revelations (ed. Dr. Dallinger.) 21 plates and 800 illus., demy 8vo. *Churchill*, 1901. (The standard work.) 28s.

HOGG, JABEZ: Microscope—History, Construction, and Application. 20 plates and 447 illus., cr. 8vo. *Routledge*, 1898. (Ranks next after Carpenter.) 10s. 6d.

SCHACHT, H.: The Microscope and its Application. (Trans.) Post 8vo. *Churchill*, 1855. (Chiefly vegetable.) 6s.

WRIGHT, LEWIS: A Popular Handbook to the Microscope. Ill., cr. 8vo. *Religious Tract Society*, 1898. (An excellent book for beginners.) 2s. 6d.

APPLICATIONS.

BEHRENS, Prof. H.: A Manual of Micro-Chemical Analysis. (Trans.) Ill., cr. 8vo. *Macmillan*, 1900. (A well-known book.) 6s.

BEHRENS, J. W.: The Microscope in Botany. (Trans.) Ill., 8vo. *Boston*, 1885. $5.

CHAMBERLAIN, C. J.: Methods in Plant Histology. Demy 8vo. *Chicago*, 1901.

CLARKE, L. LANE: Objects for the Microscope. 8 coloured plates, cr. 8vo. *Groombridge*, 1871.

Cole, H. C. (ed.): Studies in Microscopic Science. Coloured plates, 8vo. *Baillière*, 1883–86. 4 vols. Vol. I., 27s. 6d.; Vols. II., III., IV., each, 31s. 6d.

Cooke, M. C.: 1,000 Objects for the Microscope. Ill., cr. 8vo. *Warne*, 1900. (For amateurs.) 2s. 6d.

Furneaux, W.: Life in Ponds and Streams. 8 coloured plates and 331 figs., cr. 8vo. *Longmans*, 1897. 6s. net.

Gosse, P. H.: Evenings at the Microscope. Ill., cr. 8vo. *S.P.C.K.*, 1895. (Elementary. A delightfully written book.) 4s.

Griffith, J. W., and Henfrey, A.: Micrographic Dictionary (ed. Rev. M. J. Berkeley and Prof. T. R. Jones). 15 plates and 818 illus., representing 2,680 figs., 8vo. *Gurney*, 1883. (A standard work of reference.) 52s. 6d.

Kerr, R.: Hidden Beauties of Nature. Ill., 8vo. *Religious Tract Society*, 1900. 2s. 6d.

Lankester, E.: Half-hours with the Microscope. Ill., 12mo. *W. H. Allen*, 1900. 2s. 6d.

Martin, J. H.: Microscopic Objects Figured and Described. 194 illus., 8vo. *Van Voorst*, 1871. 14s.

Oertel, E. T.: Medical Microscopy. *Rochester, N.Y.*, 1903. $2.0.

'Quekett Club Man': My Microscope and Some Objects from my Cabinet. 5 illus., fcap. 8vo. *Roper*, 1888. 2s. 6d.

Scherren, H.: Ponds and Rock-pools. Ill., cr. 8vo. *Religious Tract Society*, 1894. (Good.) 2s. 6d.

Scherren, H.: Through a Pocket Lens. Ill., cr. 8vo. *Religious Tract Society*, 1897. 2s. 6d.

Shelley, H. C.: Chats about the Microscope. Ill., post 8vo. *Scientific Press*, 1899. 2s.

Slack, H. J.: Marvels of Pond-life. Ill., cr. 8vo. *O. Newman & Co.*, 1892. (Well-known book.)

Strasburger, E.: Handbook of Practical Botany. (Trans.) 149 illus., cr. 8vo. *Sonnenschein*, 1900. (Well-known book.) 10s. 6d.

Wood, Rev. J. G.: Common Objects of the Microscope. Ill., cr. 8vo. *Routledge*, 1900. (Well-known book.) 2s. 6d.

Periodicals.

American Monthly Microscopical Journal. *C. W. Smiley, Washington, U.S.* Per ann., $2.

Annual of Microscopy. *Lund Humphries.* 1899–1900. Each, 2s. 6d.

Journal of Applied Microscopy, monthly. *New York,* 1898-1903. (Discontinued.) 4d.

Journal of the Royal Microscopical Society, every two months. *Williams & Norgate.* 6s.

Journal of the Quekett Microscopical Club, every six months. *Williams & Norgate.* 3s. 6d.

Knowledge, monthly. 27, *Chancery Lane, W.C.* 6d.

Quarterly Journal of Microscopical Science, not strictly quarterly. *Churchill.* 10s.

Some of the foregoing books are out of print. In every case when the date is given it is the most recent. Only books or periodicals written in or translated into the English language are included.

APERTURE TABLE

(From the Royal Microscopical Society's Journal)

Numerical Aperture. ($n \sin u = a.$)	Corresponding Angle ($2u$) for— Air ($n = 1·00$).	Water ($n = 1·33$).	Homogeneous Immersion ($n = 1·52$).
1·52	..	..	180° 0′
1·50	..	..	161° 23′
1·45	..	..	145° 6′
1·40	..	..	134° 10′
1·35	..	..	125° 18′
1·33	..	180° 0′	122° 6′
1·30	..	155° 38′	117° 35′
1·26	..	142° 39′	111° 59′
1·24	..	137° 36′	109° 20′
1·20	..	128° 55′	104° 15′
1·10	..	111° 36′	92° 43′
1·00	180° 0′	97° 31′	82° 17′
0·98	157° 2′	94° 56′	80° 17′
0·96	147° 29′	92° 24′	78° 20′
0·94	140° 6′	89° 56′	76° 24′
0·92	133° 51′	87° 32′	74° 30′
0·90	128° 19′	85° 10′	72° 36′
0·88	123° 17′	82° 51′	70° 44′
0·86	118° 38′	80° 34′	68° 54′
0·84	114° 17′	78° 20′	67° 6′
0·82	110° 10′	76° 8′	65° 18′
0·80	106° 16′	73° 58′	63° 31′
0·78	102° 31′	71° 49′	61° 45′
0·76	98° 56′	69° 42′	60° 0′
0·74	95° 28′	67° 37′	58° 16′
0·72	92° 6′	65° 32′	56° 32′
0·70	88° 51′	63° 31′	54° 50′
0·68	85° 41′	61° 30′	53° 9′
0·66	82° 36′	59° 30′	51° 28′
0·64	79° 36′	57° 31′	49° 48′

APERTURE TABLE (*continued*).

Numerical Aperture. ($n \sin u = a$.)	Corresponding Angle ($2u$) for—		
	Air ($n = 1{\cdot}00$).	Water ($n = 1{\cdot}33$).	Homogeneous Immersion ($n = 1{\cdot}52$).
0·62	76° 38′	55° 34′	48° 9′
0·60	73° 44′	53° 38′	46° 30′
0·58	70° 54′	51° 42′	44° 51′
0·56	68° 6′	49° 48′	43° 14′
0·54	65° 22′	47° 54′	41° 37′
0·52	62° 40′	46° 2′	40° 0′
0·50	60° 0′	44° 10′	38° 24′
0·45	53° 30′	39° 33′	34° 27′
0·40	47° 9′	35° 0′	30° 31′
0·35	40° 58′	30° 30′	26° 38′
0·30	34° 56′	26° 4′	22° 46′
0·25	28° 58′	21° 40′	18° 56′
0·20	23° 4′	17° 18′	15° 7′
0·15	17° 14′	12° 58′	11° 19′
0·10	11° 29′	8° 38′	7° 34′
0·05	5° 44′	4° 18′	3° 46′

USEFUL MEMORANDA

MEASURES AND WEIGHTS.

1 millimetre = ·03937 inch.

The unit used in microscopy is the *micron*, generally written μ = ·001 millimetre.

One inch = 25·3999 millimetres.
,, = 25·4 millimetres approximately.
One foot = 30·4799 centimetres.
,, = 30·48 centimetres approximately.
One gram = 1 cubic centimetre of distilled water at 4° C.
,, = 15·432 grains.
One grain = ·064792 gram.
One ounce avoirdupois = 437·5 grains = 28·349 grams.
,, ,, apothecaries = 480 grains = 31·103 grams.
One kilogram = $2\frac{1}{5}$ lbs. avoirdupois approximately.
One cubic centimetre = 16·9 minims = $\frac{1}{16}$ cubic inch approximately.
One minim = ·05916 c.c.
One fluid drachm = 3·5495 c.c.
One fluid ounce = 28·396 c.c.
One pint = 567·92 c.c.
One quart = 1·1358 litres.
One litre = 35·2154 fluid ozs.

TEMPERATURES.

To convert Centigrade into Fahrenheit $\left(C \times \frac{9}{5}\right) + 32 = F.$

,, ,, Fahrenheit into Centigrade $(F - 32) \times \frac{5}{9} = C.$

STANDARD "SOCIETY" GAUGES.

Objectives.

Male screw ..	.. 0·8015	inch,	36 threads.
Female screw ..	.. 0·7967	,,	36 ,,

Eyepieces.

No. I.	.. ·9173 inches,	23·3	millimetres.
No. II.	.. 1·04 ,,	26·416	,,
No. III.	.. 1·27 ,,	32·258	,,
No. IV.	.. 1·41 ,,	35·814	,,

Sub-Stage.

1·527 inches, 38·786 millimetres.

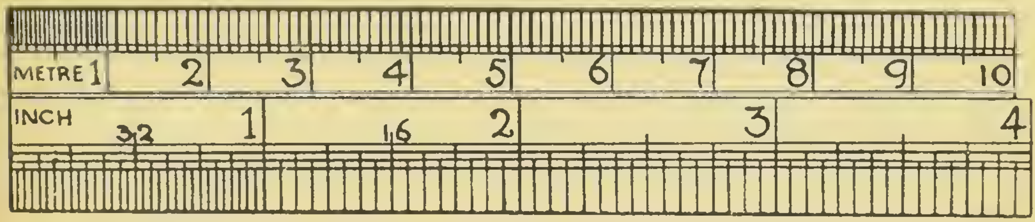

FIG. 78.—CENTIMETRE AND INCH SCALE.

INDEX

THE END

Baillière, Tindall & Cox, 8, Henrietta Street, Covent Garden.